AFWAL - TR-82-3050

RENEWABLE ENERGY SYSTEM FEASIBILITY STUDY

School of Engineering
North Carolina Agricultural and Technical State University
Greensboro, North Carolina 27411

August 1982

Final Report for period September 1980 through April 1982

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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October 18, 1982

Dr. David Klett
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Greensboro, N.C. 27411

Re: Renewable Energy System Feasibility Study, AFWAL
TR-82-3050, Air Force Wright Aeronautical Laboratory.

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A study was performed to determine the economic feasibility of displacing a portion of the electrical energy usage at the Wind Tunnel Complex at WPAFB by a renewable energy system. Wind systems, photovoltaic systems and solar thermal systems were evaluated using lifecycle cost analysis. Economic feasibility was not found for any of the systems evaluated.

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FORWORD

This report was prepared as part of Contract No. F33615-80-K-3626 between Air Force Wright Aeronautical Laboratories and North Carolina Agricultural and Technical State University. This is the final report covering work performed during the contract period 2 September 1980 through 30 April 1982. Dr. D.E. Klett of the Mechanical Engineering Department was the project director. Dr. D.Y. Goswami of the Mechanical Engineering Department and Drs. E.K. Stefanakos and D.E. Olson of the Electrical Engineering Department were co-investigators. Mr. Stanley Palmere of AFWAL/FIMN was the contract monitor. The report was released in May 1982.

The authors wish to thank Mr. David Wyrick of AFWAL/FIMN for supplying needed data on physical facilities and Capt. Peter Speck for supplying meteorological data for Wright-Patterson Air Force Base needed for the study.

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SECTION I

INTRODUCTION

1. OBJECTIVES

The primary objective of this study was to determine the feasibility of displacing a portion of the electrical energy usage associated with the operation of the wind tunnel complex of the Flight Dynamics Laboratory at Wright-Patterson Air Force Base (WPAFB). Towards achieving this primary objective, a study was performed that encompassed the following sub-objectives or tasks:

(1) Quantify the availability of wind and solar energy resources at WPAFB by gathering available meteorological data from Air Force sources and the National Weather Service and converting into formats convenient for use in evaluating renewable energy systems.

(2) Identify appropriate loads within the wind tunnel complex best suited for displacement by various types of renewable energy systems and identify the renewable energy sources and systems best suited to meet the loads.

(3) Perform a conceptual system design based on existing technology and commercially available hardware for the renewable energy systems identified as most appropriate.

(4) Establish cost estimates for the most appropriate renewable energy systems based on manufacturer supplied prices.

(5) Assess the potential for displacement of non-renewable energy by the renewable energy systems based on the renewable energy resource data and manufacturer supplied performance data.

(6) Perform a lifecycle cost analysis of the proposed renewable energy systems to provide a basis for decision on deployment of a particular system.

Several renewable energy sources were evaluated for potential applications at WPAFB. These included:

(1) Biomass
   (a) Alcohol production from agricultural crops
   (b) Methane production from agricultural waste products
(2) Wind Energy
(3) Solar Energy
   (a) Photovoltaic solar electric systems
   (b) Solar thermal energy systems

Considerable effort was expended in quantifying the availability of wind and solar energy at the site. The availability of agricultural feed stocks for biomass production was not evaluated for the Dayton area since it was decided rather early in the study that the logistics involved in delivering the necessary feed stocks to the Air Force Base for digestion or distilling into usable fuels made biomass systems inappropriate for this application. The major portion of the feasibility study thus focussed on the availability and application of wind energy and solar energy.

2. SCOPE

The following sections give details and results of the renewable resource assessment, load evaluation, available hardware assessment, system design and cost analysis. Conceptual system designs and lifecycle cost analyses were performed for three renewable energy systems, a wind system, a photovoltaic system and a solar thermal system. While the results do not indicate a positive present worth for any of the systems under reasonable assumptions for fuel escalation rates, none of the systems described are too expensive to be considered for installation on an experimental demonstration basis.

SECTION II

RENEWABLE ENERGY RESOURCE ASSESSMENT

Assessment of the renewable energy resources for WPAFB is given here under three headings: 1. General climatological data, 2. Solar energy resource and 3. Wind energy resource.

1. GENERAL CLIMATOLOGICAL DATA

Climatological data for Dayton, Ohio was obtained from References 1-5. This data represents observations made by the National Weather Service station at the James M. Cox (Dayton Municipal) Airport located approximately 20 miles from WPAFB. Additional climatological data for the Base was supplied by AFWAL/FIMN including extensive wind pattern data. Table 1 gives long-term monthly average values of climatological data that is of significance in solar system design.

The majority of the climatological data was obtained from Reference 1 and is given as monthly and annual averages of data recorded over several decades through 1977. For exact years of record and other details consult Reference 1. Two values are given in the tables for relative humidity, one for morning (M) taken at 7 a.m. and one for afternoon (A) taken at 1 p.m. The maximum wind velocity data includes the direction of the highest recorded wind and the annual value given is simply the highest value recorded. More extensive wind data is given in Table A-5 and Figures 1 and 2 discussed later.

The dewpoint temperature and the annual percentage frequency of wind by speed groups were obtained from Reference 2.

Heating and cooling degree days (65°F base) and winter and summer design temperatures are reproduced from Reference 3 to aid in determining building heating and cooling loads. The design temperatures are 99 percent and 1 percent dry bulb

TABLE 1

Climatological Data for Dayton

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	UNITS
% Sunshine	41	46	49	53	60	67	67	69	66	61	42	38	57	
Days Clear	5	5	5	5	6	7	8	9	10	11	5	4	.	
Days PCLDY	6	6	7	8	10	10	12	12	9	8	7	7	102	
Days CLDY	20	17	19	17	15	13	11	10	11	12	18	20	183	
Snow/Sleet	8.3	5.9	5.6	.7	T	0.0	0.0	0.0	0.0	0.1	2.5	5.8	28.9	in.
Rel Hum(M)	76	76	78	76	77	79	81	86	86	81	80	79	80	%
Rel Hum(N)	70	69	66	59	57	58	59	64	66	65	72	75	65	%
Dew Point	23	24	29	39	50	58	62	61	54	44	33	24	42	DEG F
Max. Temp.	35.8	38.6	48.1	61.7	72.0	81.6	84.7	83.4	77.0	66.0	50.1	38.3	61.5	DEG F
Min. Temp.	20.4	22.1	29.9	41.0	51.2	61.0	64.4	62.6	55.5	44.9	33.4	23.4	42.5	DEG F
Avg. Temp.	28.1	30.4	39.0	51.4	61.6	71.3	74.6	73.0	66.3	55.5	41.8	30.9	52.0	DEG F
Freeze Days	27	24	18	6	*	0	0	0	*	4	14	24	117	
Heating DD	[illegible]	964	761	291	151	19	1	6	70	335	655	1001	5508	DD
Cooling DD	0	0	1	16	72	210	311	269	125	16	0	0	1020	DD
Wind Vel.	8.6	10.2	10.1	9.9	8.4	7.7	6.8	6.5	7.0	7.6	9.2	9.7	8.6	KNOTS
VMax, Wind	[illegible]	66SW	70W	60S	61SW	78NW	52W	49SW	65W	56SW	57SW	47S	78NW	MPH

99% Winter Design Temp. = -1°F 99% Summer Design Temp.= 91°F

Wind Speed	(0-3)	(4-6)	(7-10)	(11-16)	(17-21)	(22-27)	(> 28) KNOTS
% Frequency	7.5	29.0	35.2	24.0	3.7	0.5	0

values meaning that on the average the winter design temperature is exceeded 99 percent of the time and the summer design temperature is exceeded 1 percent of the time.

The total hemispherical radiation on horizontal surfaces appearing as the first entry in the climatological table are predicted values determined through the use of regression models by the National Climatic Center of the National Oceanic and Atmospheric Administration (NOAA). They were obtained from Reference 4.

2. SOLAR ENERGY RESOURCE

a. Tables of Average Day Radiation Values

Average day values of solar insolation on stationary surfaces with various tilt and azimuth angles and on an altazimuth tracking surface are given in Appendix A, Table A-1. Both beam and total radiation values are given. The diffuse component (including ground reflected radiation) can be obtained by subtracting the beam component from the total value.

The tables of solar radiation values for tilted surfaces were obtained through the use of the SIM computer program based on a solar insolation model originally developed at Martin Marietta Corporation for NASA [6]. This program was modified by the authors for improved accuracy and smoother monthly transitions.

The model uses percent sunshine or cloud cover data to predict solar insolation values for locations where no measured radiation data exists.

Dayton is one of the 222 derived SOLMET data stations for which total horizontal insolation values have been developed by NOAA using regression models and long-term monthly average percent sunshine, opaque cloudiness and sky condition data [7]. The SIM model was applied using the percent sunshine data for the Dayton Municipal Airport with monthly values of Clearness

Number chosen to reproduce the NOAA derived values for total horizontal insolation from Reference 4.

The modified SIM model used to generate the insolation values for this study is described below:

b. Solar Insolation Model

To calculate insolation values, a day (from sunrise to sunset) is divided into 100 parts. A number of these parts equivalent to the percent sunshine (PS) are assumed totally clear. The remaining parts (100-PS) are assumed totally cloudy. The totally cloudy parts are evenly distributed over the entire day. The instantaneous solar irradiance is calculated for each of these parts which is then integrated to give the value for the whole day. The values are thus calculated for each day of the month and then averaged to give the average daily insolation (beam, diffuse, reflected, total) for the month. The instantaneous irradiance on a horizontal surface for totally clear and totally cloudy conditions are calculated as follows:

(1) Totally clear (Horizontal Surface)

Beam Irradiance $H(b) = I \cos \theta$

where

θ = Solar Incident Angle

I = Normal Incident Beam Irradiance

$I = CnI_o e^{-\tau} \sec \theta$

I_o = Extraterrestrial Solar Irradiance

τ = Optical Depth due to absorption and scattering by the atmosphere

Cn = Clearness Number - a parameter to account for the variation in τ from the average conditions

Diffuse Irradiance H(d) = $C\ I/(Cn)^2$

where C = Sky Diffuse Factor

Total Irradiance H(t) = H(b) + H(d)

(2) Totally Cloudy (Horizontal Surface)

Beam Irradiance H(b) = 0

Diffuse Irradiance H(d) = $(H(t)_{clear})$ (CCF)

where CCF = Cloud Cover Factor

The relations for calculating the irradiance on a surface tilted at an angle to the horizontal are purely geometrical and will be omitted here. However, for a surface tilted at an angle to the horizontal, the ground reflected irradiance must also be included, which is calculated as follows:

$$\text{Ground Reflected Irradiance } H(r) = \rho_g[H(b) + H(d)][1-\cos(PT)]/2$$

where ρ_g = Ground Reflectivity

PT = Panel Tilt Angle

The ground reflectivity was assumed to be 0.2 for this study. Values of Cn were calculated for each month to account for the seasonal variation in C according to the following equation.

$$Cn = \frac{H(t)\ (\text{NOAA published value from Reference 4})}{H(t)\ (\text{calculated for } Cn = 1)}$$

c. Table of Clear Day Radiation Values

A knowledge of the level of solar radiation to be expected on totally clear days is helpful in the design of solar energy systems, both photovoltaic and thermal. For this reason a table of clear day radiation values on a south facing surface with various tilt angles and on tracking surfaces was generated using the SIM program assuming 100 percent sunshine and using the monthly Clearness Numbers calculated for Dayton as described above. These values are given in Table A-2.

d. Tables of Hourly Radiation Values

The daily distribution of solar radiation is also of interest in solar system design. Hourly values of solar radiation were calculated with the SIM program for the middle day of each month for a fixed surface facing due south with a 40° tilt angle and for an altazimuth tracking surface. Table A-3 gives average day values based on long-term weather observations and Table A-4 gives clear day values based on 100 percent sunshine.

3. WIND ENERGY RESOURCE

Wind velocity data was obtained from the NOAA National Weather Service at the Dayton Municipal Airport [5] and from WPAFB. The NOAA data is included in Table A-5 as excerpted from Reference 5. The wind velocity distributions contained in this data have been used to compute the wind power curves shown in Figure 1. These curves show the yearly average of wind power density in kilowatts per square meter plotted versus the hour of the day at which that yearly average occurred.

The NOAA data constitutes the most complete source for wind velocity distribution information and, therefore, has been chosen to be the principle data base for wind power evaluation (this is the line connected data in Figure 1). The information presented in Figure 1 shows that, depending on the location of the wind measuring instrumentation, maximum wind power at WPAFB occurs at about 1400 hours in the day and may be expected to vary from between 40% below to 20% above the wind power existing at the Dayton Municipal Airport.

Figure 2 shows the average monthly power density derived from the NOAA data for each month. The long-term average annual power density is 0.114kw/m^2.

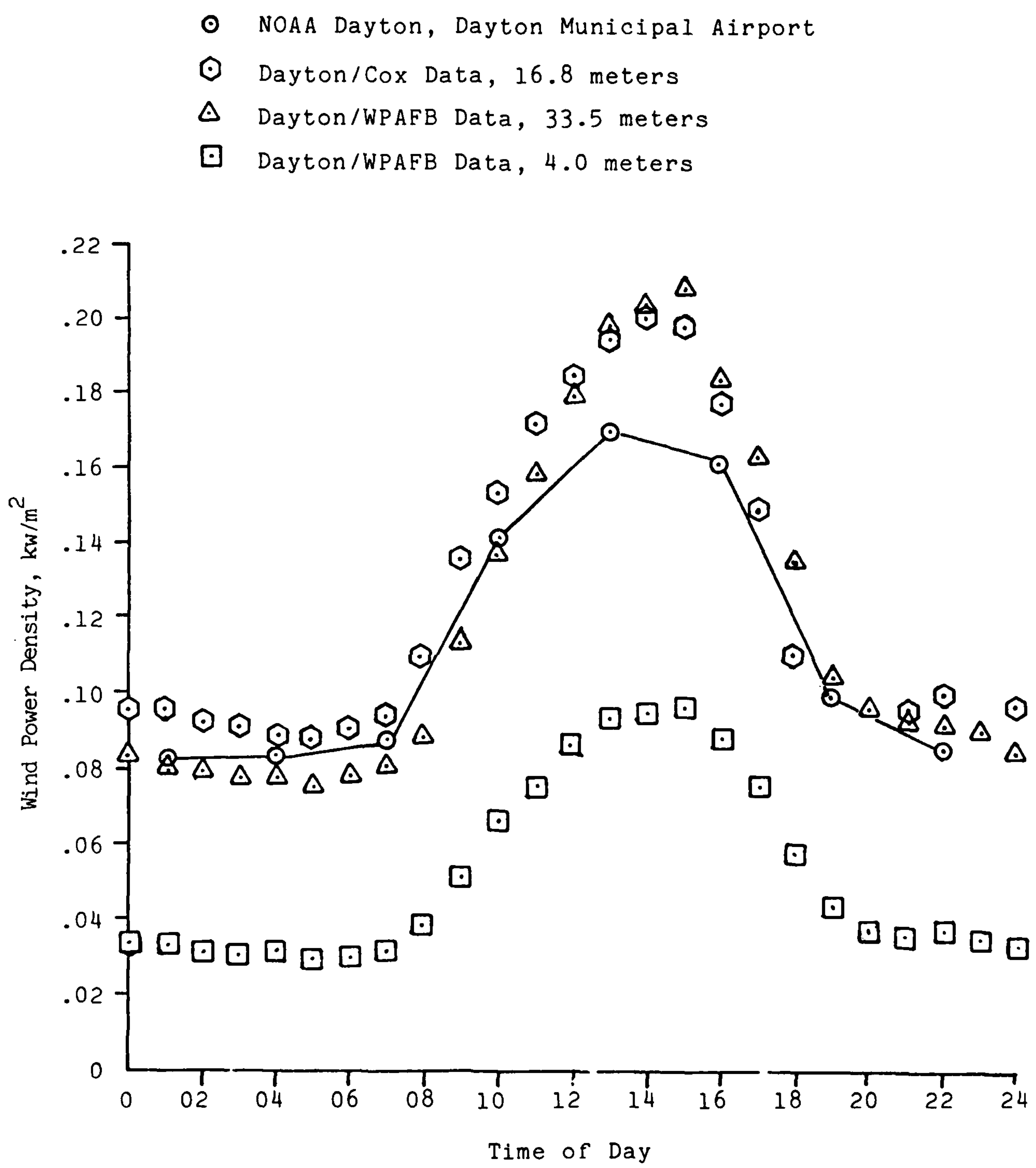

Figure 1. Wind Power Density Versus Time of Day From Various Sources.

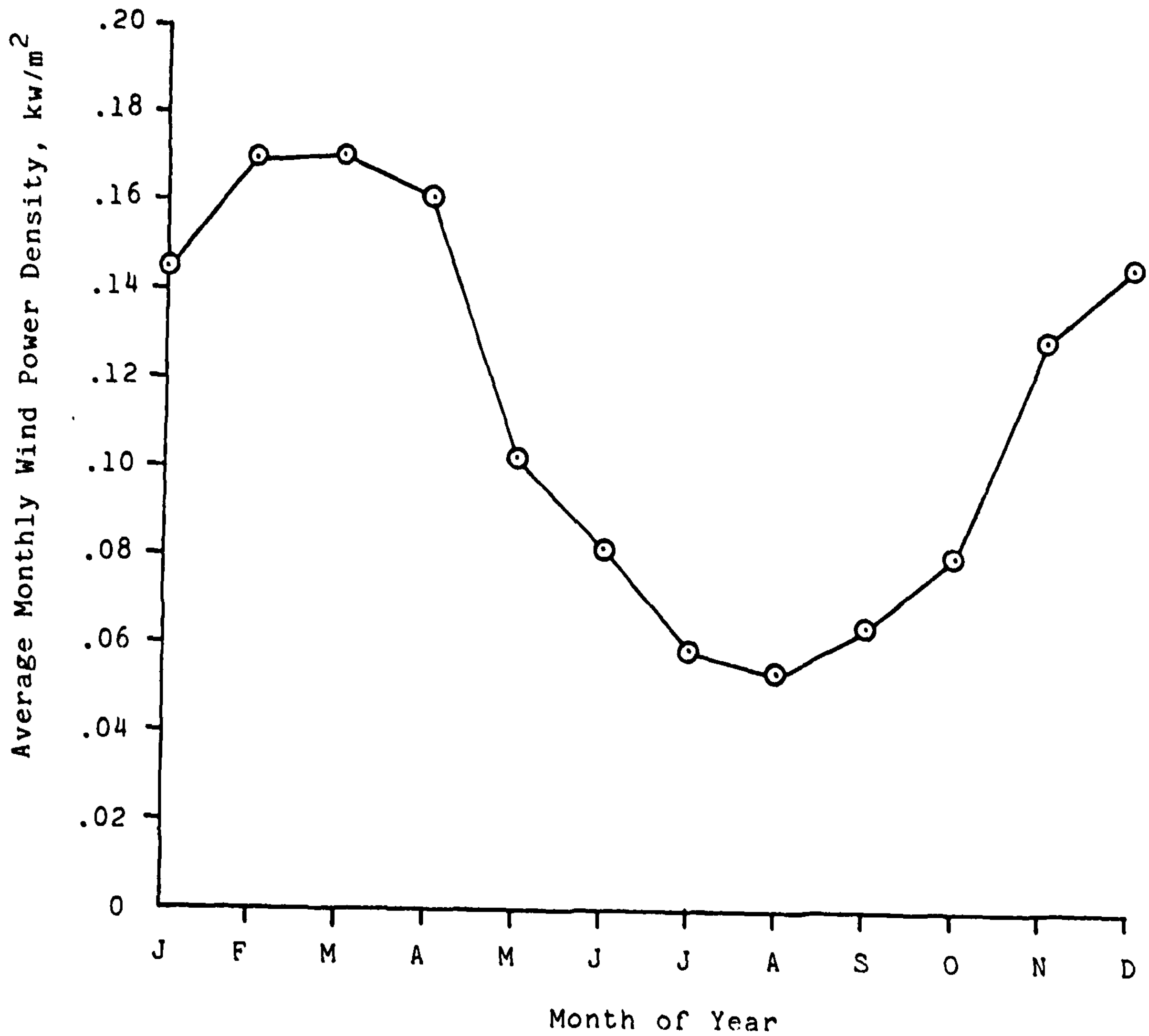

Figure 2. Average Monthly Wind Power Density

SECTION III

LOAD IDENTIFICATION

Eight distinct electrical loads at the wind tunnel complex were initially identified by AFWAL/FIMN personnel for consideration as potential loads for renewable energy systems. These included:

(1) A 60 kw electrical heater for the Instrument Air Dryer System

(2) The 120 volt D.C. Supply Battery System

(3) A 100 HP air compressor

(4) A 40 kw air conditioner

(5) A 250 kw diesel generator set

(6) Two 5 ton air conditioners

(7) A 250 kw load to the motor control centers

(8) A 26 kw air conditioner at the Vertical Wind Tunnel.

Of these potential loads, the first two were deemed the most suitable for further evaluation. In addition, the physical configuration and unobstructed wind access of the Vertical Wind Tunnel (VWT) suggested it as a possible site for a wind generator system. Thus, the electrical load pattern of the VWT was also investigated and consideration was given to a wind generator system to meet this load. In the final analysis, the feasibility of a wind energy system to supply power for the VWT was less than that of a wind generator to charge the D.C. Supply Battery System. Details of the VWT electrical load will thus be omitted from this report while details on the Instrument Air Dryer electrical heater and the D.C. Supply Battery System are given below.

1. D.C. SUPPLY BATTERY SYSTEM

The D.C. Supply Battery System provides D.C. current for switching gear and D.C. oil pumps for wind tunnel blower lubrication. The system consists of 20 Exide 3CC-9 200 amp/hour batteries with a nominal system voltage of 130 volts. The load on the batteries is typically about 4 amps when testing is in progress and the oil pumps are in use which can last for periods of up to 8 hours per day. There is a constant small load on the battery system from indicator lights. Operation of switching gear represents spike loads to the battery system.

The batteries are currently charged on a continuous basis at between 1 and 2 amps by a motor-generator set. This load, while not large (approximately 6.24 kwh per day), is most feasible for displacement by a wind or photovoltaic electrical system due to its constant and predictable nature.

2. INSTRUMENT AIR DRYER

The Instrument Air Dryer (IAD) system is used to supply very dry air (dewpoint of -30°C) for instrumentation and pneumatic controls use. Two desiccant beds are used to dry the air. The drying beds are used on alternate days with one bed being regenerated while the other is providing dry air. Each desiccant tank contains 1400 pounds of H-151 activated alumina $\frac{1}{4}$" balls. Regeneration of the desiccant is accomplished by circulating heated air at approximately 177°C (350°F) through the desiccant tank at a rate of 220 scfm.

The heated air for the regeneration cycle is currently being produced with a nominal 60 kw electrical resistance heating element. The heater, which actually draws 56 kw, is controlled by a thermostatic on-off controller. During operation the heater cycle is typically on for 1.25 minutes and off for 2.0 minutes. Air enters the heater at about 25°C (75°F) and leaves with a time varying temperature that cycles between 150°C to 195°C (300°F to 380°F). The heated air enters the desiccant bed with an average temperature of 172°C

(340°F) and absorbs moisture from the desiccant. The exit air temperature from the desiccant bed gradually increases during the drying cycle to 120°C (250°F) at which point the heater is turned off. This process requires approximately six hours and consumes an average of 128 kwh of electricity.

A schematic diagram of the IAD system is shown in Figure 3. The system is controlled manually by a technician who switches valves ADV-8 and ADV-9 and activates the electric heater at the beginning of each work day. The heater is turned off in the afternoon when the exit air temperature reaches the prescribed 120°C (250°F). Since the energy requirement for desiccant drying is thermal energy, the IAD represents the most appropriate load to be displaced by a solar thermal system.

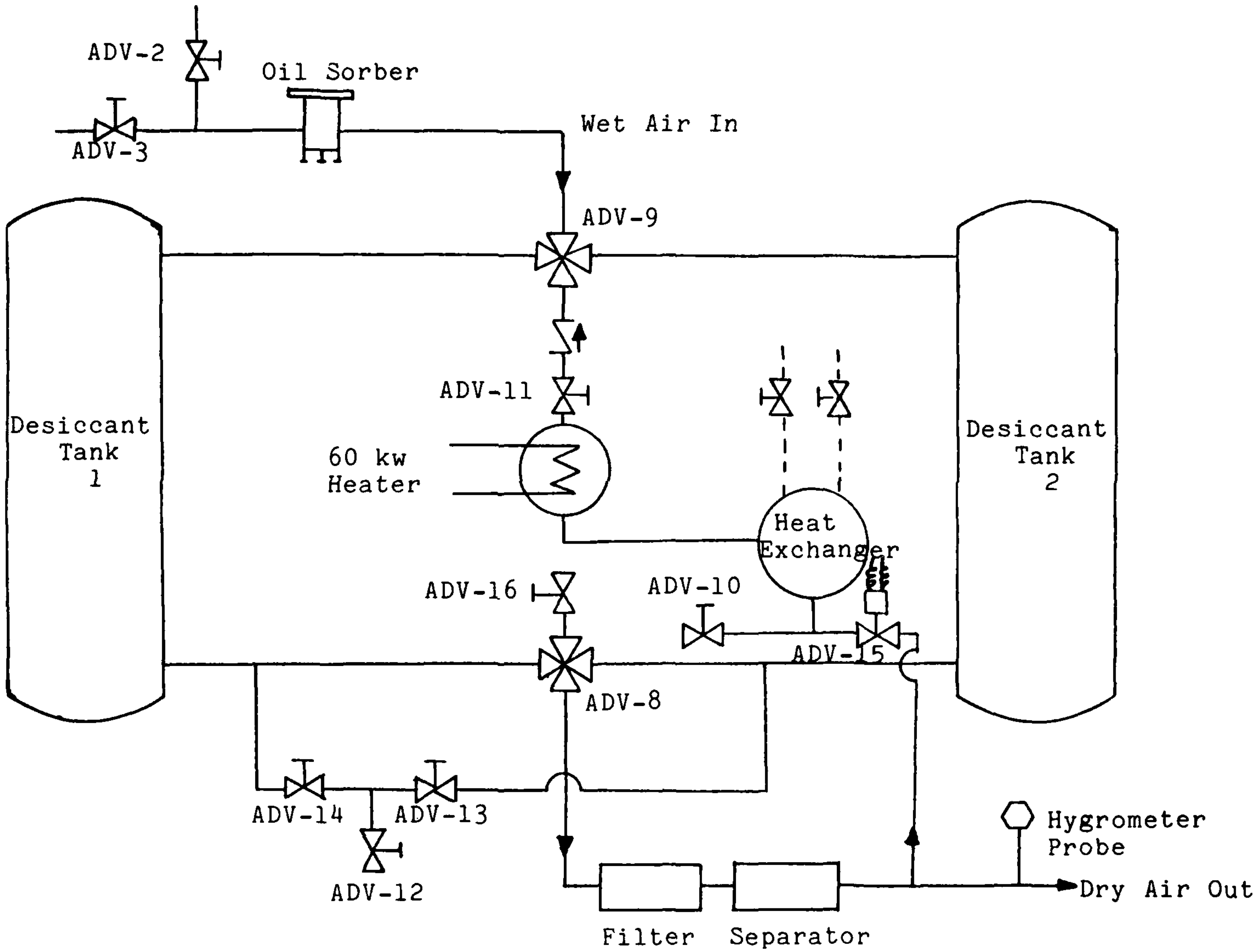

Figure 3. Schematic of Instrument Air Dryer System

SECTION IV

PHOTOVOLTAIC POWER SYSTEM

1. LOAD SELECTION

During the study, photovoltaic power systems were designed for two loads, the D.C. Supply Battery System and the Vertical Wind Tunnel lighting, instrumentation and controls. Details of the system design for the VWT were given in the monthly report for April 1981 and the Interim Report [8]. The economics for this system are extremely poor due to the highly variable nature of the load and the concurrent need for a battery storage subsystem to meet the load.

The D.C. Battery Supply, on the other hand, represents an ideal load for a photovoltaic system. Even though the economics for this ideal application do not warrant installation of the system from a Cost/Benefit Viewpoint, details of the system sizing and cost analysis are presented here because the system is not overly expensive and might be considered as an emergency charging system for the battery bank in the event of an extended power failure as occurred at the base in October 1981.

For the purpose of sizing a photovoltaic system, it was assumed that 6 amperes will be required at 130 volts over an 8-hour daylight period to provide the 6.24 kwh per day required to charge the batteries.

2. DESIGN METHOD

The design method developed by Evans, et. al. [9] was adopted for sizing the photovoltaic systems for this feasibility study. It provides fairly accurate and detailed results and allows the solar fraction to be predicted for a given array size.

The method predicts the photovoltaic array and system performance for a passively cooled, flat, south facing, maximum power tracked array for meeting the requirement of a specific use pattern electrical load. The parameters needed to evaluate the performance of the PV array are: monthly average array efficiency, monthly average array insolation and monthly average array and power conditioning output. The above parameters are briefly described below.

a. Array Thermal Performance

The efficiency for rejecting thermal energy to the surroundings is an important property of the array. This is important since the operating efficiency of an array is primarily a function of temperature. A commonly cited parameter that contains information on this efficiency is the Nominal Operating Cell Temperature or NOCT. The efficiency of heat rejection is given by means of a loss coefficient, U_L, which is dependent on the solar absorptance (α) of the photovoltaic array. The design procedure used in this report requires knowledge of either NOCT or U_L/α.

b. Array Reference Efficiency

Under conditions of maximum power operation, the actual conversion efficiency of the array, η, is approximately linearly related to cell temperature T_c by

$$\eta = \eta_r \, [1-\beta(T_c - T_r)]$$

where η_r is a reference array or module efficiency for converting solar energy to electrical output when the cells in the array are at a stated temperature T_r. β is a temperature coefficient and can be calculated by using two different efficiencies at two different cell temperatures using the relation

$$\beta = \frac{1-(\eta_2/\eta_1)}{T_2 - T_1}$$

c. Power Conditioning

η_{pc} is the power conditioning efficiency. The power conditioning may include provisions for utility interconnection, conversion from D.C. to A.C. and battery efficiency.

d. Monthly Average Potential Array and Power Conditioner Output

The monthly average daily energy output per unit area of array (including power conditioning losses) is given by

$$QE/A = \frac{\eta_{pc}}{100} \cdot \frac{\eta}{100} \cdot QS/A$$

where QS/A is the monthly average daily insolation on a unit area of the array.

The following part of this design procedure introduces three important parameters.

L - Monthly average daily electrical load

B - Electrical energy storage capacity

F - Solar fraction or the portion of the electrical load supplied by the photovoltaic system.

e. Load

This number is determined by the application and is the amount of electrical energy (kwh) that a photovoltaic power system might be required to supply daily.

f. Electrical Storage Capacity

This electrical storage can be a bank of chemical batteries or any other means of storage. When batteries are used, the electrical energy storage capacity, B (in watt hrs.), is calculated from:

B[wh] = Capacity Per Battery [Ah] x Average Voltage Per Battery [v] x Fraction Of Battery Used x Number Of Batteries Used.

Here the "Fraction Of Battery Used" depends upon how deep a discharge and how high a charge are permitted during battery operation. For example, if 60% of total available battery capacity is utilized, this factor would be 0.6.

g. Solar Fraction

This is the fraction of the load that is met by the photovoltaic system. The quantities discussed above are combined to give the variables which are necessary to eventually obtain solar fractions. These variables are:

$$QE/L = (QE/A) \cdot (1/L) \cdot A$$

and

$$B/A\eta = \frac{1}{\eta} \cdot B \cdot \frac{1}{A} \cdot \frac{(QS/A)_{lat}}{QS/A} \cdot \frac{90}{\eta_{pc}}$$

where: QE/L is the potential solar fraction in that it represents the fraction of the load which could potentially be satisfied by electrical energy from the array if infinite, loss free storage were available (due to losses in the battery or dumping of extra power, F is always less than QE/L). $B/A\eta$ is a dimensional ratio of storage capacity to the product of array area and monthly average array efficiency. The values of the above two variables are used to enter the appropriate system performance curves from Reference 9 which best describe the application load profile. The curves provide the predicted value of solar fraction.

3. PHOTOVOLTAIC MODULE CHARACTERISTICS

The photovoltaic module chosen for the basis of the battery charging system is the Power Module No. 60-3040 manufactured by Applied Solar Energy Co. The required cell operating characteristics (from Reference 10) and assumed array parameters are given below.

η_r = 10.36% at T_r = 28°C and Insolation = 1 kw/m^2

β = 0.0045 °C^{-1} (for silicon cells)

NOCT = 47°C at 1 kw/m^2, Ta = 20°C and Wind Speed of 1m/s

η_{pc} = 90% (assuming maximum power tracking and a three phase inverter)

S_m = Optimum array tilt angle = 40°

S = Latitude = 39.9°

4. DETERMINATION OF SOLAR FRACTION VERSUS ARRAY SIZE

The D. C. Supply System consists of 20 Exide 3cc-9 200 amp-hour batteries with a nominal system voltage of 130 volts. The total battery capacity to be used in the design of the photovoltaic system is, therefore, 200 x 130 = 26,000 watt-hours. Assuming a depth of discharge factor of 0·6 the total battery capacity, B, available is 26,000 x 0·6 = 15,600 watt hours.

Worksheet 1 indicates typical calculations required in the design procedure. Assuming a photovoltaic array size, the fraction of energy supplied by solar, F, can be calculated as a function of QE/L and the pre-determined battery capacity. Using the values of QE/L and $B/A\eta$ from columns C-16 and C-17 of the worksheet, the monthly values of F were estimated from Figure 4 and entered in column C-18. Finally, the annual value of F for a particular array area (in this example $A\eta = 13m^2$) is calculated as shown in Worksheet 2-A for average day conditions and Worksheet 2-B for clear day conditions.

Various values of F corresponding to different values of A can be calculated by repeating the steps outlined in Worksheets 1 and 2. Using this procedure a plot of F versus A was generated for average day and clear day conditions as shown in Figure 5. To supply 100% of the load under average day conditions would require about $20m^2$ of array. However, due to inaccuracies in the array sizing method as the fraction contributed by solar exceeds 0.8, it is wise to choose an area of about $13m^2$ of photovoltaic array. This size will be sufficient to supply all of the energy requirements during the month of June for a clear day and about 82% of needed energy for the entire year under average weather conditions as indicated in Figure 5.

5. PV SYSTEM BLOCK DIAGRAM

Figure 6 shows a block diagram for a PV System. The

WORKSHEET 1

Location DAYTON

Latitude 39.9 N

T_r = 28 [C]

η_r = 10.36 [%]

β = 0.0045 [C^{-1}]

η_{pc} = 90.00 [%]

NOCT = 47 [C] 1.00 kW/m², T_a = 20 [C] or U_L/α = — kW/(m²·C)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Month	WS [m/s] from Table	KT from Table	s_M from Table (degrees)	s designer's choice (degrees)	$= \lvert s-s_M \rvert$ $\lvert C4-C3 \rvert$ (degrees)	TM [C] from Table	T_c from Fig. 2.1	η[%] from Eq. 2.2 $\eta_r[1-\beta(C7-T_r)]$	QS/A [kWh/m²]	OE/A [kWh/m²] $= \frac{\eta_{pc}}{100} \cdot \frac{C8 \cdot C9}{100}$
JAN	5.27	0.37	68.9	39.9	29.0	-21.60	-13.0	12.27	2.69	0.297
FEB	5.27	0.42	57.9	39.9	18.0	-00.84	11.0	11.15	3.51	0.350
MAR	5.49	0.43	42.9	39.9	03.0	03.89	14.0	11.01	4.16	0.410
APR	5.27	0.47	29.9	39.9	10.0	10.78	22.0	10.64	4.76	0.460
MAY	4.43	0.49	17.9	39.9	22.0	16.44	28.0	10.36	5.13	0.480
JUN	4.06	0.51	14.9	39.9	25.0	21.83	34.0	10.08	5.22	0.470
JUL	3.62	0.51	15.9	39.9	24.0	23.63	37.0	09.94	5.16	0.460
AUG	3.35	0.52	29.9	39.9	10.0	22.78	39.0	09.85	5.19	0.460
SEP	3.71	0.50	37.9	39.9	02.0	19.06	33.0	10.13	4.88	0.440
OCT	4.07	0.48	49.9	39.9	10.0	13.06	26.0	10.45	4.13	0.390
NOV	5.01	0.39	72.9	39.9	23.0	05.44	19.0	10.77	2.73	0.260
DEC	5.14	0.35	69.9	39.9	30.0	-00.61	08.0	11.29	2.29	0.230

WORKSHEET 2-A

A = 13 [m²] (designer's choice)

B = 15,600 [WH] (designer's choice)

	C11	C12	C13	C14	C15	C16	C17	C18	C19
Month	d	QE/A [kWh/m²] from WORKSHEET 1	η[%] from WORKSHEET 1	$(QS/A)_{lat}$ [kWh/m²] from Table	L [kWh]	QE/L $= \frac{C12 \cdot A}{C15}$	B/Aη [Wh/m²%] $= \frac{B}{A \cdot C13} \cdot \frac{C14}{C9} \cdot \frac{90}{\eta_{pc}}$	F from C16, C17 in TABLE	L·d [kWh] = C11·C15
JAN	31	0.30	12.27	2.69	6.24	0.625	97.79	0.60	193.44
FEB	28	0.35	11.15	3.51	6.24	0.729	108.99	0.73	174.72
MAR	31	0.41	11.01	4.16	6.24	0.854	111.32	0.85	193.44
APR	30	0.46	10.64	4.76	6.24	0.958	114.83	0.68	187.20
MAY	31	0.48	10.36	5.13	6.24	1.000	117.99	1.00	193.44
JUN	30	0.47	10.08	5.22	6.24	0.979	121.33	0.98	187.20
JUL	31	0.46	09.94	5.16	6.24	0.958	122.45	0.96	193.44
AUG	31	0.46	09.85	5.19	6.24	0.958	121.83	6.96	193.44
SEP	30	0.44	10.13	4.88	6.24	0.917	118.46	0.92	187.20
OCT	31	0.39	10.45	4.13	6.24	0.813	114.83	0.813	193.44
NOV	30	0.26	10.77	2.73	6.24	0.542	111.42	0.54	187.20
DEC	31	0.23	11.29	2.29	6.24	0.479	106.29	0.48	193.44

$$\text{Annual F} = \frac{\sum (F \cdot L \cdot d)}{\sum (L \cdot d)} = \frac{\sum (C18 \cdot C19)}{\sum C19} = \frac{1863.2}{2277.6} = 0.818$$

WORKSHEET 2-B

A = 13 [m²] (designer's choice)

B = 15,600 [Wh] (designer's choice)

	C11	C12	C13	C14	C15	C16	C17	C18	C19
Month	d	QE/A [kWh/m²] from WORKSHEET 1	η[%] from WORKSHEET 1	$(QS/A)_{lat}$ [kWh/m²] from Table	L [kWh]	QE/L $= \frac{C12 \cdot A}{C15}$	$B/A\eta$ [Wh/m²%] $= \frac{B}{A \cdot C13} \cdot \frac{C14}{C9} \cdot \frac{90}{\eta_{pc}}$	F from C16,C17 in TABLF	L·d [kWh] = C11·C15
JAN	31	0.615	12.04	5.68	6.24	1.280	99.67	1.00	193.44
FEB	28	0.656	11.01	6.62	6.24	1.370	1C8.99	1.00	174.72
MAR	31	0.706	10.78	7.28	6.24	1.470	111.32	1.00	193.44
APR	30	0.714	10.45	7.59	6.24	1.490	114.83	1.00	187.20
MAY	31	0.677	10.17	7.40	6.24	1.410	117.99	1.00	193.44
JUN	30	0.633	09.89	7.11	6.24	1.320	121.33	1.00	187.20
JUL	31	0.617	09.80	7.00	6.24	1.285	122.45	1.00	193.44
AUG	31	0.622	09.80	7.05	6.24	0.390	122.45	1.00	193.44
SEP	30	0.629	10.03	6.97	6.24	1.310	119.64	1.00	187.20
OCT	31	0.621	10.31	6.09	6.24	1.290	116.39	1.00	193.44
NOV	30	0.599	10.77	5.77	6.24	1.250	111.42	1.00	187.20
DEC	31	0.501	10.83	5.14	6.24	1.040	110.80	1.00	193.44

$$\text{Annual F} = \frac{\sum (F \cdot L \cdot d)}{\sum (L \cdot d)} = \frac{\sum (C18 \cdot C19)}{\sum C19} = \frac{2277.6}{2277.6} = 1.0$$

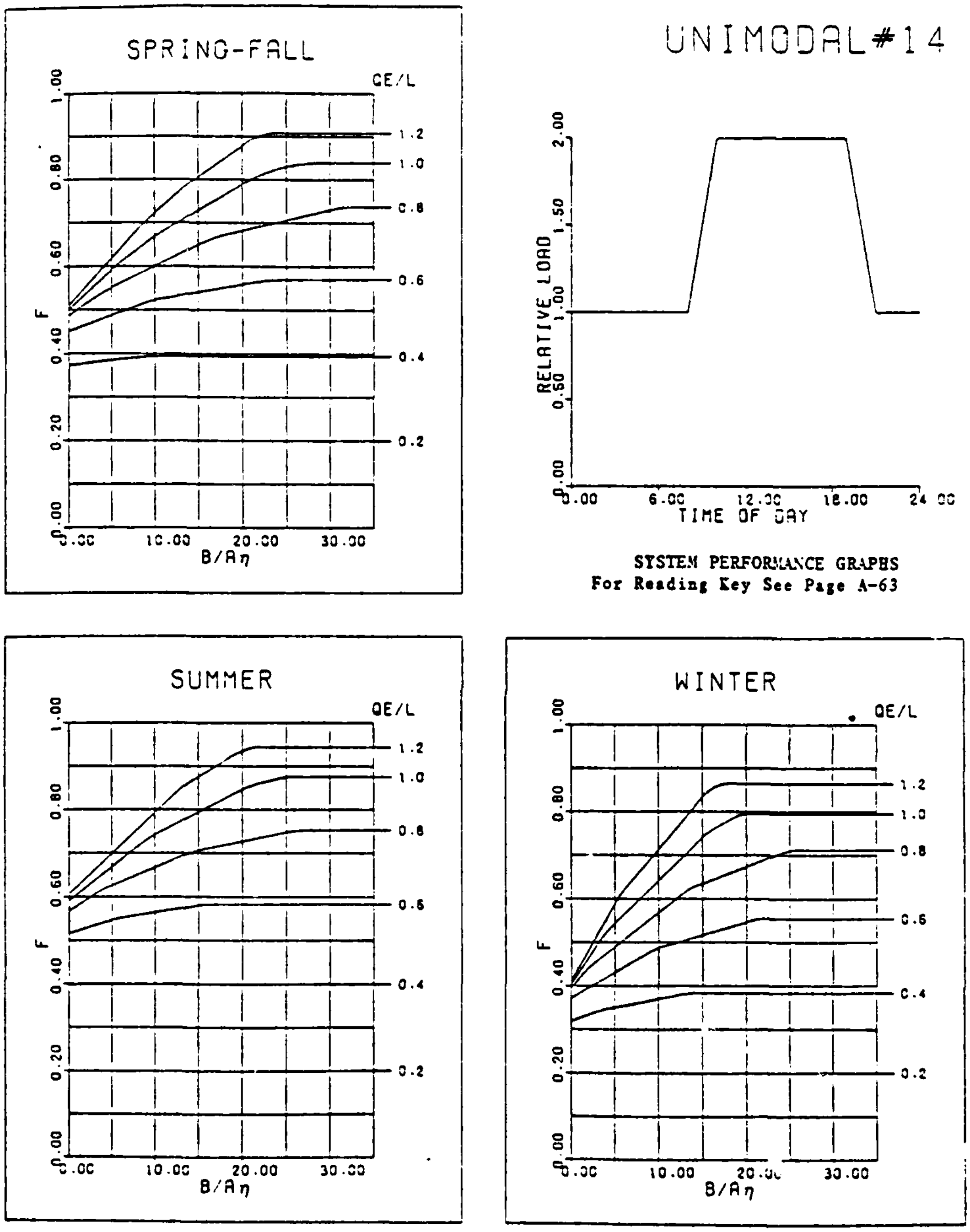

Figure 4. System Performance Graphs For Sizing Photovoltaic Systems (From Reference 9).

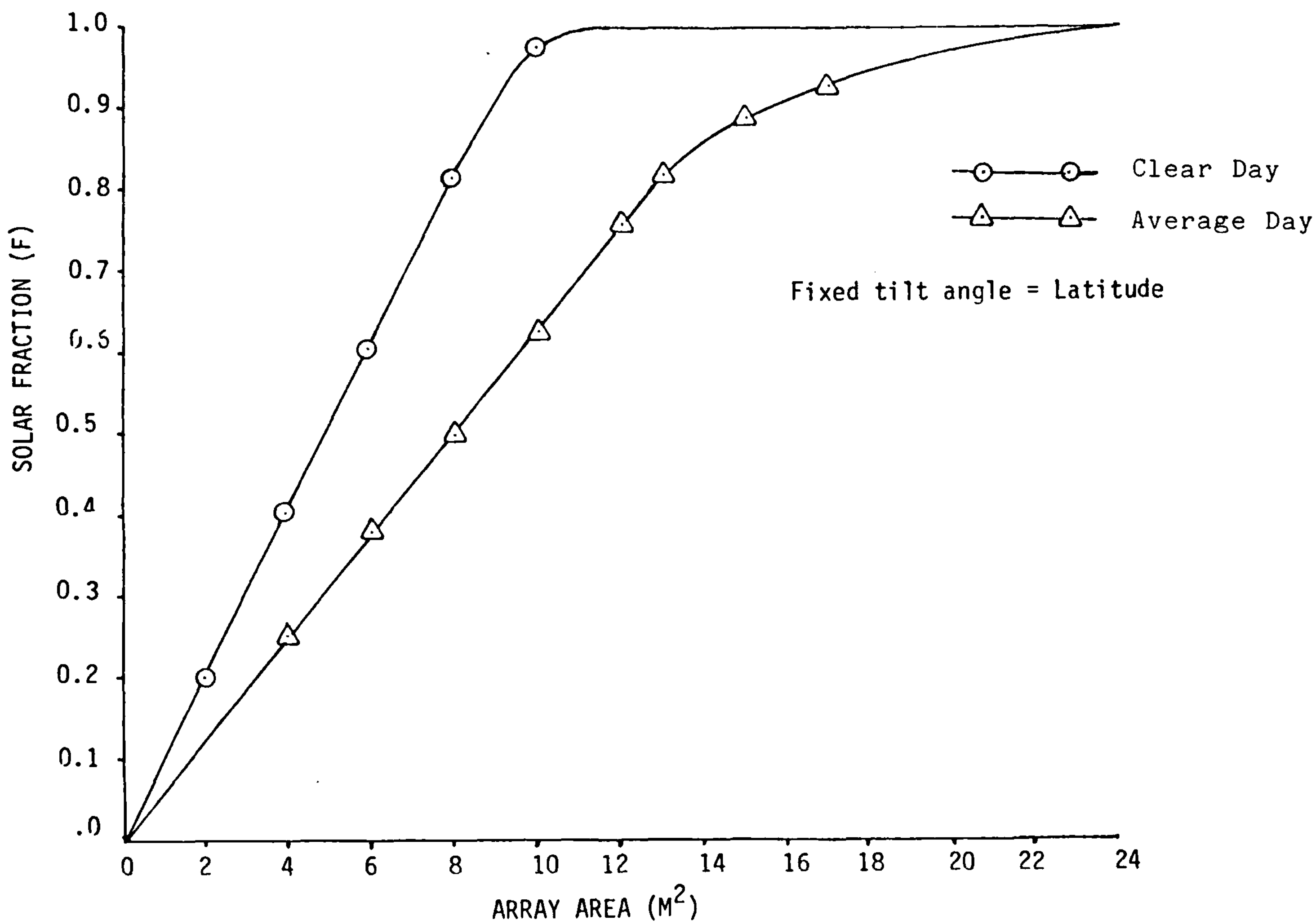

Figure 5. Variation of Solar Fraction as a Function of Array Area for the Photovoltaic Battery Charging System.

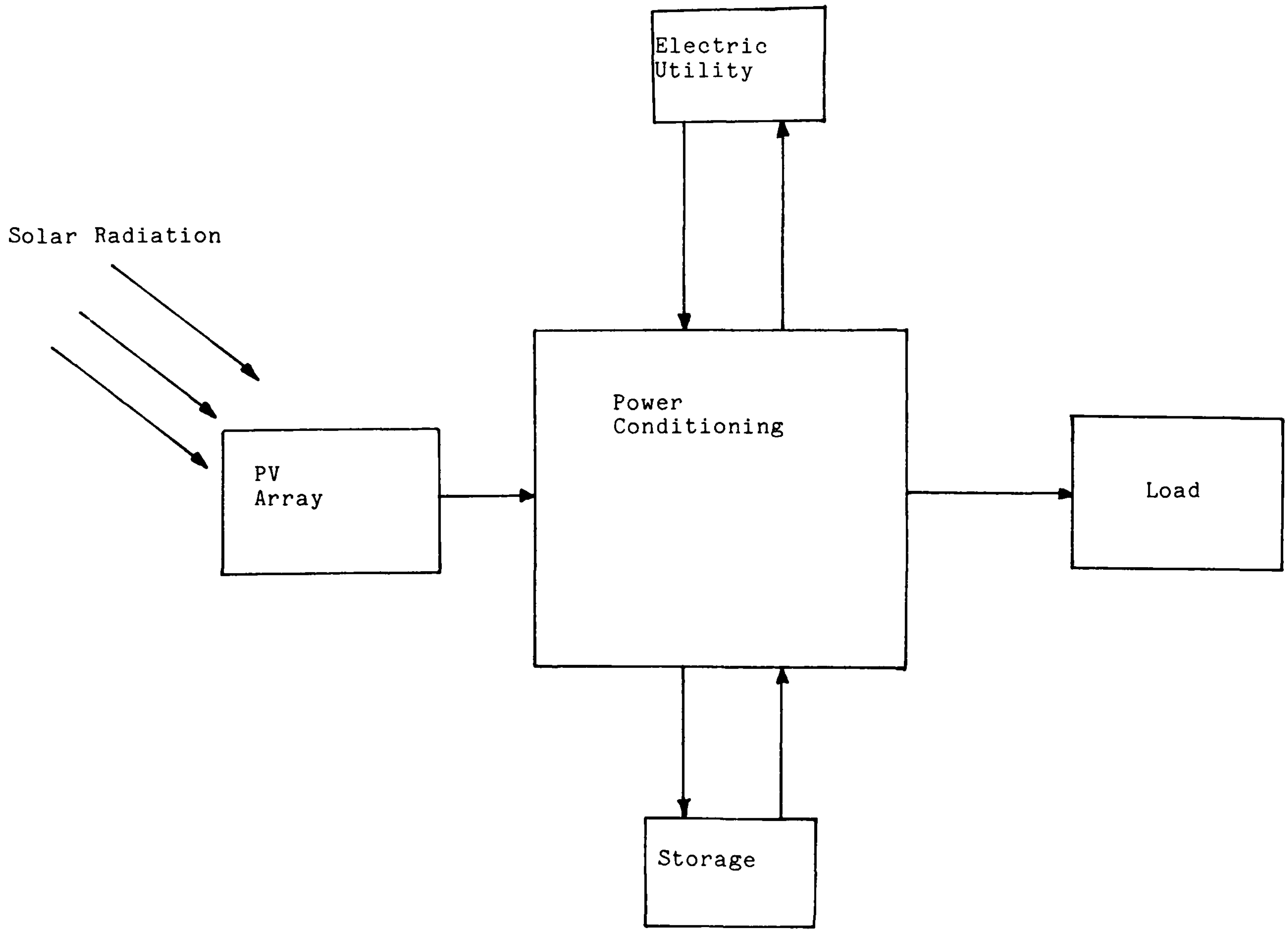

Figure 6. Block Diagram for PV System.

collected solar energy is used by the photvoltaic modules to generate electrical output. This electrical energy is utilized for the load. The system components are:

Photovoltaic Array Modules: These are the solar cells connected in series and parallel combinations depending on the output requirements.

Power Conditioning: This subsystem has the D. C. output of the arrays as input and its functions are:

- Conversion of D. C. to A. C. if required (here A. C. is not necessary as D. C. is required to charge the batteries).
- Regulation of the power to the load
- Power tracking, i.e., the operation of PV arrays at the maximum power point
- Battery interface which includes a battery charger
- Utility interface

Storage: The existing bank of 20 Exide 3cc-9 batteries.

Electric Utility: This provides backup energy when the PV system is not operating or during bad weather conditions when PV output is low.

Load: This is the sink to the regulated electrical power from the PV array, batteries and/or utility.

6. ECONOMIC ANALYSIS FOR PV SYSTEM

Economics is a key factor in determining the viability of a photovoltaic power system. As with any solar energy system, a PV system offers the benefits of future energy cost savings based on an initial investment in equipment. Thus, a complete analysis requires the evaluation of both benefits (B) and costs (C) over the useful life of the system.

Since the cash flows depend on time, for the correct evaluation of PV system economics, it is necessary to estimate the values of all savings and costs that accrue over time and convert these values to an equivalent amount at a single point in time. The method for accomplishing this is called present value analysis or lifecycle analysis.

The system chosen for the cost analysis has $13m^2$ of array area capable of supplying 5.1 kwh/day (solar fraction ≅ 0.82) to the battery storage system. The cash flow parameters considered for the economic analysis are

E - Annual energy savings

P - Purchase and installation costs

M - Annual maintenance and repair costs

R - Major replacement costs

S - Salvage value.

The above parameters are used to obtain the net present value of the PV system. The following assumptions were made in determining the present value:

- System lifetime - 20 years
- Battery and Power Conditioner lifetime - 10 years
- Discount rate - 15%
- Escalation or inflation rate - 15%

<u>Annual Energy Savings (E)</u>

Since the system displaces 5.1 kwh/day, the annual savings in electrical energy is 5.1 x 365 x utility rate ($/kwh). Assuming a current average utility rate of $0.0525/kwh then

$$\text{Annual Savings} = 5.1 \times 365 \times \$0.0525 = \$97.73/\text{year}.$$

for a discount rate of 15% and escalation rate at 15%, over 20 years, the total energy savings is

$$E = \text{UPW}(15,15,20Y) \times \$97.73 = 20 \times \$97.73 = \$1{,}954.00.$$

where UPW (15,15,20Y) is the uniform present worth over 20 years at 15% discount rate and 15% escalation rate. The cost analysis has been performed for two values of cost per peak watt (W_p) for the PV modules.

<u>Case 1</u> - $/peak watt = $10.00

Assuming a 10% array efficiency, $1m^2$ of array supplies 100 peak watts (W_p) of energy; therefore, $13m^2$ of array provides 1300 W_p.

Purchase and Installation Costs (P)

Purchase and installation costs are divided into two parts, hardware costs and indirect costs. The hardware cost is subdivided into the following costs [9]:

Array cost: $\$10/W_p \times 1300\ W_p = \$13{,}000$

Array structure cost: $\$140 + 0.3 \times 1300\ W_p = \$530$

Power conditioner costs: $\$1.2 \times 1300 = \$1{,}560$

Since the storage batteries and building already exist at the site, the costs associated with these are not considered in the analysis. The indirect costs include the engineering, installation and management costs. The management costs are neglected while the indirect costs [10] are assumed to be 45% of the hardware cost or 0.45 ($13,000 + $530 + $1,560) = $6,790. Therefore, the purchase and installation cost is:

$$P = \$13{,}000 + \$530 + \$1{,}560 + \$6{,}790 = \$21{,}880.$$

Maintenance and Repair Costs (M)

The first year maintenance and repair costs are assumed to be 1.0% of the original purchase and installation cost [10]. Over a 20-year lifetime, the maintenance and repair costs are:

$$\begin{aligned} M &= 0.01 \times \$21{,}880 \times \text{UPW}\ (15,15,20Y) \\ &= .01 \times \$21{,}880 \times 20 \\ &= \$4{,}376 \end{aligned}$$

Major Replacement Costs (R)

The replacement cost for the power conditioner after 10 years is estimated by [11]

$$R = (0.263 \times W_p)$$

so $R = \$0.263 \times 1300\ W_p$

$$R = \$342$$

Assuming a salvage value of zero, the total system cost, C, is the sum of the purchase and installation costs, the maintenance cost and the replacement cost

$$C = P+M+R = \$21{,}880 + \$4{,}376 + \$342 = \$26{,}598$$

Since the benefit, B, equals the total energy savings E of \$1,954, the net present value of the system for a PV module cost of \$10/W_p is

$$B-C = \$1,954 - \$26,598$$
$$= -\$24,644$$

Case 2: \$/peak watt = \$2.80

Purchase and Installation Costs (P)

As described in the first case, the hardware costs are:

Array cost = \$2.8/W_p x 1300 W_p = \$3,640,

Array structure cost = \$530 as in the previous case,

Power conditioner costs = \$1,560 as in the previous case.

The indirect costs are again 45% of the hardware costs, i.e., 0.45 (\$3,640 + \$530 +\$1,560) = \$2,579. Therefore, the purchase and installation costs are

$$P = \$3,640 + \$530 + \$1,560 + \$2,579 = \$8,309.$$

Maintenance and Repair Cost (M)

The same maintenance and repair cost is assumed as in the previous case

$$M = \$4,376$$

Major Replacement Costs (R)

The power conditioner replacement cost after 10 years is the same as in the previous case

$$R = \$342$$

Again assuming a zero salvage value, the system cost is

$$C = P+M+R = \$8,309 + \$4,376 +\$342$$
$$= \$13,027$$

Therefore, the net present value of the system for PV modules at \$2.80/W_p is

$$B-C = \$1,954 - \$13,027$$
$$= -\$11,073$$

7. CONCLUSIONS

In both cases examined, the net cash flow for a 20-year system lifetime is negative. Current cost of photovoltaic arrays is approximately \$10 per peak watt. At this price, the net present value of the proposed system is a negative

$24,644. The price of PV modules may be expected to fall to about $2.80 per peak watt in the next few years. Even at this price the net present value of the system represents a loss of about $11,000.

On the basis of the above cost analysis, one can conclude that photovoltaic systems, at this time, are not cost competitive with conventional power sources. Installation of a photovoltaic array to provide part of the energy needs for the D. C. Battery System could be justified only on the basis of demonstrating alternative energy usage and acquiring experience with photovoltaic power systems, or on the basis of providing emergency battery charging in the event of a power failure.

SECTION V

WIND ENERGY SYSTEM

1. PRELIMINARY WORK

Manufacturers information was initially obtained on 16 wind generators. Five of these were chosen for an initial estimate of economic feasibility. The machines, representing a wide range of rated output, were: Aerowat 4.1 kw, Millville 10 kw, Jay Carter 25 kw, Mehrkam 100 kw and Mehrkam 225 kw. The output curves from these five machines were applied to the available wind power resource depicted in Figure 2 to obtain the expected annual energy production assuming the availability of infinite storage. A preliminary lifecycle cost analysis was then performed based on the expected installation and maintenance cost of each of the machines and the value of energy produced.

Details of this analysis were provided in the Interim Report [8] and are included in Appendix B for completeness. The results of the preliminary economic analysis on the five machines indicated rather large negative present values rendering all five machines uneconomical.

Subsequent to this initial effort a wind generator was found that is well matched to the load presented by the D. C. Supply Battery System. This machine is described below along with a lifecycle cost analysis of an application to charge the D. C. Battery System. Although the present value of this system is still negative over a 20 year lifetime the cost is not too great and the system could be considered for deployment on an experimental basis.

2. WIND SYSTEM SELECTION

The energy requirement to keep the D. C. Battery System charged is approximately 6.24 kwh per day or an average power demand of 0.26 kw. A wind turbine capable of meeting this load is the Whirlwind Model 3120 produced by the Whirlwind Power Company of Denver, Colorado. This firm submitted one of its earlier models for testing at the DOE Rocky Flats Test Facility in the Fall of 1980. This machine demonstrated that it was capable of producing the advertised rated output. One major machine failure occurred during a test in a 50mph wind which caused the rotor to overspeed and destroy the generator. Models currently produced by this manufacturer now include a "sidewheel" yaw mechanism to prevent failures of this nature by rotating the machine orthogonal to the wind direction during high wind conditions.

According to the manufacturer's description, the Whirlwind Model 3120 is specifically designed for use in 120 Volt battery charging applications. The information provided by the manufacturer on the Model 3120 is presented in Appendix C. Compared to other wind generators investigated during this study and reported on in the Interim Report, the Whirlwind 3120 comes the closest to satisfying the selected battery bank load demand with a minimum cost of installation.

The 3120 machine outputs a variable frequency, variable amplitude, three-phase AC electrical output which is then transmitted (3-phase) to a remotely located control box. The control box either inverts the 3ϕ AC to produce a 120 VDC minimum signal for battery charging, or allows the AC to be taken off for water or space heating. A charging regulator, priority selection, brake switch and full metering are all included. The manufacturer also claims the unit is virtually vibration-free and at a distance of 100 ft. produces almost no audible acoustic noise.

A synchronous inverter and utility interface can also be installed with the unit to allow power feedback into the existing AC utility network. This option, however, is considered inappropriate due to the inclination of Test Facility personnel to attempt to make use of all ancillary generated power and avoid contractural arrangements on power buy-back with Dayton Power and Light Co.

3. PREDICTED ENERGY OUTPUT AND LOAD MATCH

Applying the Whirlwind 3120 machine input-output characteristics to the wind energy distributions shown in Figures 1 and 2 results in the average yearly power available by hour of day shown in Figure 7 and the average monthly power shown in Figure 8. These curves show that the maximum power occurs during daylight hours between 0700 and 1900 hours and the maximum average daily power occurs between November and April. Some highlights of the information contained in these curves are presented in Table 2 as a performance summary.

An indication of the match between wind generated power and load power demand can also be obtained from the curves shown in Figures 7 and 8. For an average load power requirement of 0.26 kw, the wind generator is predicted to provide 100% of this load from October through June, with 80% to 94% of the load demand provided from July through September.

The efficiency of the Model 3120 machine is also indicated in Figures 7 and 8. Comparing the actual machine output to that obtainable from a 100% aerodynamically efficient Ideal Machine results in an overall efficiency of approximately 45% for the Model 3120 generator.

TABLE 2

Performance Summary

Whirlwind Model 3120

Power Rating	3.000 kw
Max. Avg. Power at 1300 Hours	0.646 kw
Min. Avg. Power at 0100 Hours	0.315 kw
Max. Avg. Power in March	0.631 kw
Min. Avg. Power in August	0.205 kw
Avg. Yearly Power	0.432 kw

Avg. Energy 10.37KwH/Day, 315.3KwH/Month, 3784KwH/Year

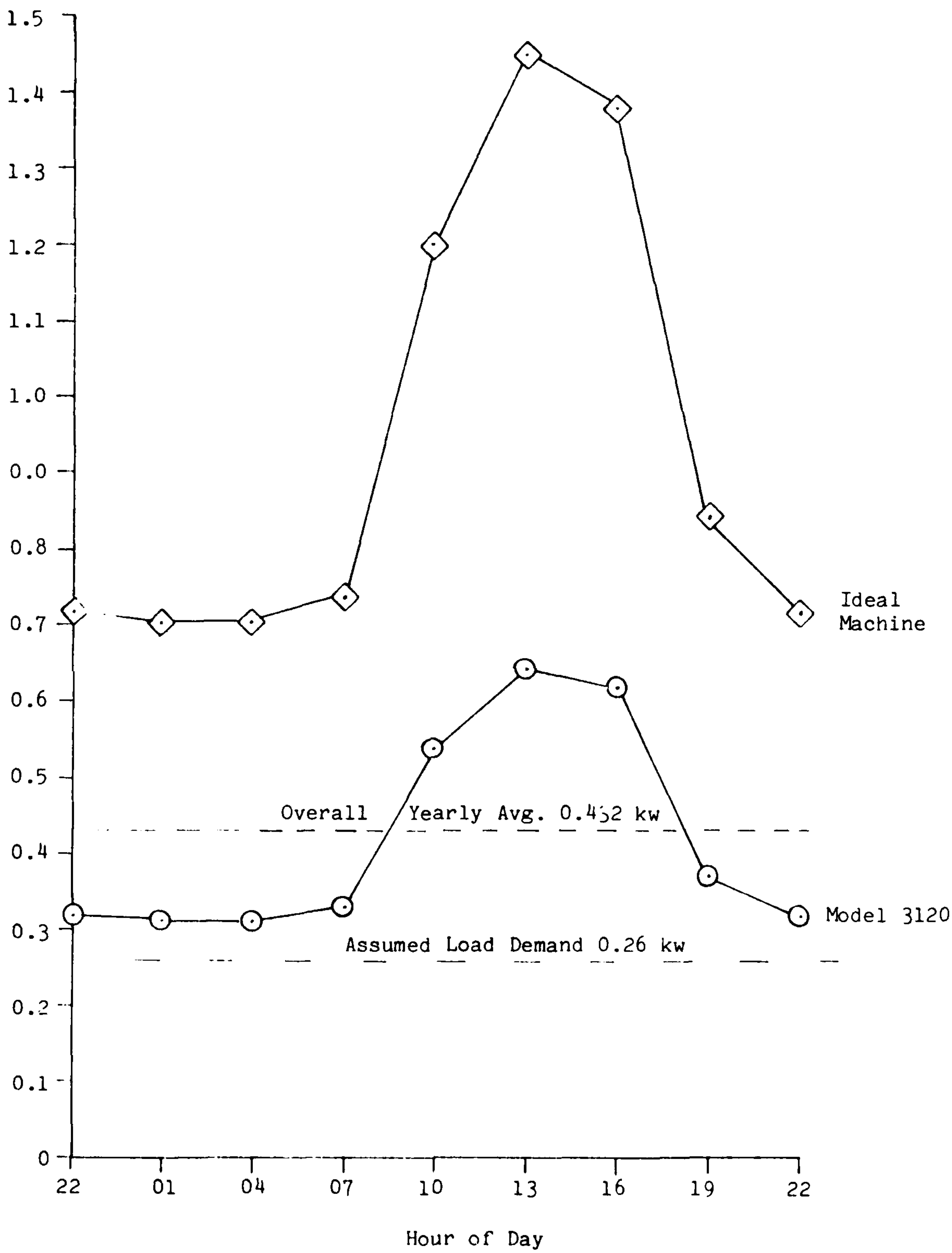

Figure 7. Average Yearly Power Versus Hour of Day For Whirlwind Model 3120 Wind Generator

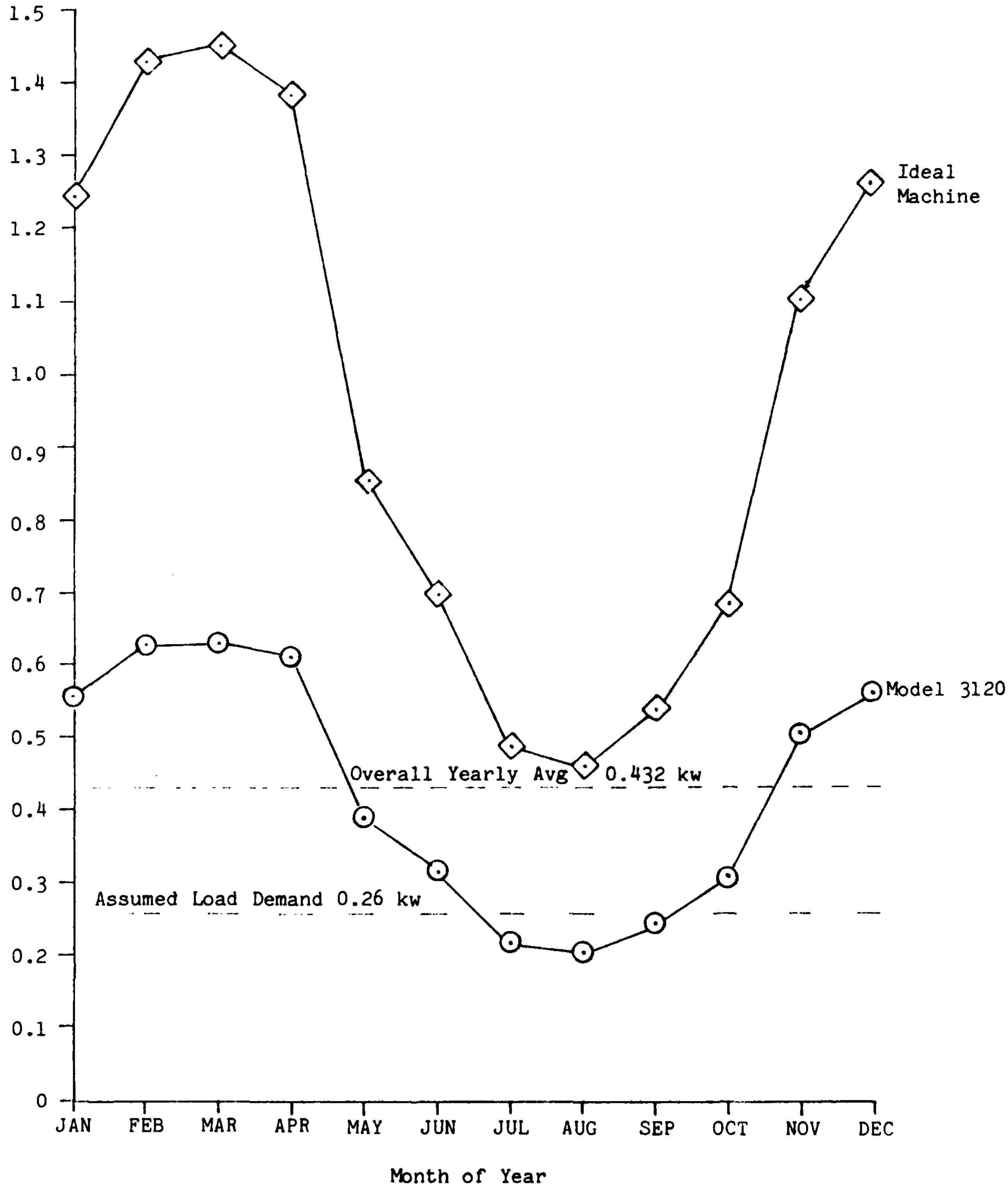

Figure 8. Average Monthly Power Versus Month of Year
Whirlwind Model 3120 Wind Generator

4. ECONOMIC COST/BENEFIT ASSESSMENT OF WHIRLWIND 3120

An assessment of the economic value of the Model 3120 wind generator was made by determining the cash flow which would result by combining the annual costs incurred with the annual funds generated if the energy produced by the machine were sold at a commercial energy rate of \$0.0525/KwH (approximate cost of energy at WPAFB). The machine was assumed to have a useful life of 20 years. The cost of money was set at 15%. Annual operation and maintenance were assumed to be 2.5% of the installed cost and allowed to escalate at 15%.

Table 3 contains the data concerning initial costs, maintenance costs and energy produced benefits.

TABLE 3

Economic Assessment

Whirlwind Model 3120

Assumed Useful Life	20 years
Base Price	\$3,600.
Tower (30ft. Free-Standing Pole)	\$1,560.
Installation (estimated)	\$2,500.
Total Purchase and Installation Cost (P)	\$7,660.
Major Replacement Cost is Assumed Zero	0
Salvage Value is Assumed Zero	0
Annual Operation and Maintenance (2.5% of P)	\$ 192.
Annual Value of Energy Generated (\$0.0525/KwH)	\$ 199.

As in the economic analysis for the photovoltaic system, the present value of the wind system is given by

$$B-C = E-(P+M+R+S)$$

Where $E = \$199 \times UPW\ (15,15,20Y) = \$199(20) = \$3,980$

$P = \$7,660$

$M = \$192 \times UPW\ (15,15,20Y) = \$192 \times 20 = \$3,840$

$$R = 0$$

$$S = 0$$

Then

$$B\text{-}C = \$3{,}980 - (\$7{,}660 + \$3{,}840) = -\$7{,}520$$

The wind generator, unlike the photovoltaic system, should displace sufficient energy to pay for any needed maintenance and repairs. However, the initial capital investment would not be recovered over the 20-year expected lifetime of the machine under the assumed conditions of equal discount and inflation rates.

SECTION VI

SOLAR THERMAL SYSTEM

1. LOAD FOR SOLAR THERMAL SYSTEM

The most appropriate load to be supplied by a solar thermal system at the wind tunnel complex of the Flight Dynamics Laboratory is the Instrument Air Dryer (IAD) system.

The IAD system represents an ideal load for a solar thermal energy system for several reasons. Among these are (a) the energy requirement is for the purpose of generating heated air which is an application well suited to a solar energy system, (b) the energy requirement is constant throughout the year which provides high utilizability of the available solar radiation, (c) the energy is required during normal working hours only, which coincides with maximum solar availability and obviates the need for energy storage, thus greatly simplifying the system and (d) the temperature requirement of 175°C air is within the performance capabilities of concentrating solar collectors. Also, use of a solar thermal energy system to regenerate the desiccant beds of the IAD would satisfy the major objective of this study, that is to displace the use of electrical energy with a renewable energy source. For these reasons, a solar thermal energy system has been designed to supplement the existing electrical heater for drying the desiccant in the IAD system.

2. SYSTEM DESIGN

a. Collector Selection

The objective of the solar thermal energy system for the IAD is to heat air for desiccant drying to a temperature of 175°C (350°F). The air flow rate is approximately 220 scfm or 16.2 lbm/min through the desiccant bed undergoing regeneration.

Solar thermal energy collectors are classified according to the heat transfer medium employed as either air-cooled or liquid-cooled. Collectors are further classified by type as either concentrating or nonconcentrating (flat plate). Nonconcentrating collectors can be eliminated from consideration for the IAD system since they are incapable of sustaining the high temperature required. The objective of supplying heated air would suggest the use of air-cooled collectors; however, liquid-cooled concentrating collectors are much more common especially when designed to operate in the temperature range of interest here. Liquid-cooled concentrating collectors are available which are capable of sustained operation at temperatures of up to 300°C. Table 4 lists several manufacturers of such equipment.

Concentrating collectors manufactured by the companies listed in Table 4 were evaluated for performance and quality for possible use with the IAD system. Collectors manufactured by Solar Kinetics Inc. (SKI) were chosen as the basis for the solar thermal desiccant drying system for the IAD.

TABLE 4

Partial List of Manufacturers of Concentrating Liquid-Cooled Solar Collectors

AAI Corporation, Baltimore, MD
Acurex Solar Corporation, Mountain View, CA
Alpha Solarco, Cincinnati, OH
American Solar King Corporation, Waco, TX
Energy Design Corporation, Memphis, TN
General Electric Company, Philadelphia, PA
General Solar Systems, Youngstown, OH
Hexcel Corporation, Dublin, CA
Solar Kinetics, Inc., Irving, TX
SUN-HEET, Inc., Denver, CO

These collectors are manufactured from high quality materials and the company has been involved in many solar industrial process heat applications including a heating and air conditioning system for the Fort Hood Army Dental Clinic. The cost of the system components is well defined making it possible to estimate the system cost with reasonable accuracy.

Concentrating liquid-cooled collectors by other manufacturers are also potential candidates, particularly those manufactured by Acurex Solar Corporation which are very similar in design to the SKI collectors. If and when a decision is made to deploy a solar thermal desiccant drying system, the system will undoubtedly be offered for bids. The bidding process could conceivably result in a less expensive system than the one described here.

Technical data sheets on the SKI collectors are given in Appendix D. The collectors are constructed using N/C machined cast aluminum bulkheads, extruded aluminum edge formers, monocoque sheet metal mirror substrate fabricated from 0.040 in. T-6 aluminum covered with 3-M FEK-244 metalized acrylic film. The receiver tube is 16-gauge steel. It has an absorbing surface of electroplated black chrome over bright nickel with 0.96 absorptivity and 0.12 emissivity. The receiver is surrounded by a pyrex glass tube creating a sealed annulus filled with dry air.

b. System Size

The thermal energy requirement for desiccant drying can be calculated from the electrical energy usage of a typical drying cycle. The electrical heater has a measured power requirement of 56kw (68 amps at 476 volts, 3 phase) and a duty cycle of 38% (heater is activated 38% of the time during a drying cycle). Assuming a 90% exchange efficiency to the heated air results in a time averaged energy requirement of 19.15kw thermal (65,365 BTU/hr) delivered to the air. For the typical six-hour drying cycle the total electrical energy consumption is 128kwh and the assumed thermal energy transfer to the air is 115kwh thermal (392,190 BTU).

This rate of energy addition is sufficient to heat 220 scfm of air from 21°C to 177°C (70°F to 350°F).

Table A-3 gives hourly average day solar radiation values on tracking surfaces for each month. Both direct beam and total (beam plus diffuse plus reflected) values are given. The data is based on long-term average total horizontal radiation and percent sunshine data for Dayton. The values were calculated with the SIM computer program described earlier. Similarly, Table A-4 gives clear day radiation values on tracking surfaces generated with the SIM model assuming 100 percent sunshine. From these two tables, the data in Table 5 has been generated. Table 5 gives both the clear day and the average day beam radiation for the six-hour period centered about solar noon. Only beam radiation is considered since concentrating collectors do not capture any significant amount of diffuse radiation. The six-hour period of solar noon ± 3 hours represents the available time for desiccant regeneration within the normal work day.

From the instantaneous efficiency curve for the SKI T-700 FEK collector (given on page 93 in Appendix D) with an operating condition of 220°C (400°F) above ambient, the collector efficiency is 64%. Assuming an additional 14% loss associated with the heat exchanger and piping an overall system thermal efficiency of 50% is predicted. This efficiency will pertain to fluid operating temperatures on the order of 205°C to 250°C (400°F to 480°F) depending on the ambient temperature which is assumed to range between -18°C to 27°C (0°F to 80°F).

The collector area required should be chosen to meet the demand on totally clear days since no energy storage is to be incorporated in the system. On a clear December day with 50% collection efficiency 2.48kwh per m^2 of collector area can be delivered to the air during a six-hour period. The SKI T-700 collector has an aperture area of

$13m^2$. A four-collector system is recommended, providing a total area of $52m^2$ (560 ft^2). Thus, in December, 129kwh of energy can be delivered on a clear day. This is slightly greater than the 115kwh required for drying but very few days each month are totally clear and the 14kwh predicted excess may be required to compensate for otherwise unaccounted for parasitic losses.

The average annual energy production from a four-collector array can be calculated from the six-hour total average day beam radiation data in Table 5. Multiplying the daily total for each month by the number of days in the month and the 50 percent system efficiency gives the monthly totals and annual total of 532kwh presented in Table 6.

TABLE 5

Tracking Surface Six-Hour Total Beam Radiation For Clear and Average Days

Month	Average Day Tracking Six-Hour Total Beam Radiation kwh/m^2	Clear Day Tracking Six-Hour Total Beam Radiation kwh/m^2
1	2.32	5.29
2	2.48	5.60
3	2.78	5.64
4	2.92	5.59
5	3.30	5.37
6	3.55	5.14
7	3.32	5.02
8	3.67	5.04
9	3.46	5.16
10	3.18	5.36
11	2.21	5.17
12	1.78	4.96

TABLE 6

Monthly Total Beam Radiation and Monthly Energy Collected

Month	Tracking Monthly Total Long-Term Average Direct Beam Radiation (Six-Hour Daily Collection) kwh/m^2	Useful Monthly Energy Collected kwh/m^2
1	71.92	35.96
2	69.44	34.72
3	86.18	43.09
4	87.60	43.80
5	102.30	51.15
6	106.50	53.25
7	102.90	51.45
8	113.80	56.90
9	103.80	51.90
10	98.58	49.29
11	66.30	33.15
12	55.18	27.59
Annual Total	1,064.50	532.25

c. System Configuration

A schematic diagram of the solar thermal system is shown in Figure 9. Four SKI T-700 collectors are connected in series on an east-west axis. The collectors are north-south tracked by a single drive unit and control unit furnished by SKI. The tracking unit is hydraulically actuated eliminating backlash. Two speed tracking is provided for rapid stow and deployment. The collectors are stowed in an inverted position at night and during storms. Sufficient hydraulic pressure is stored by the tracking system to provide stowing power in the event of utility power loss.

Collector mirror assemblies are pylon mounted to concrete piers (24" dia. x 5' depth) for ground mounting. The center-

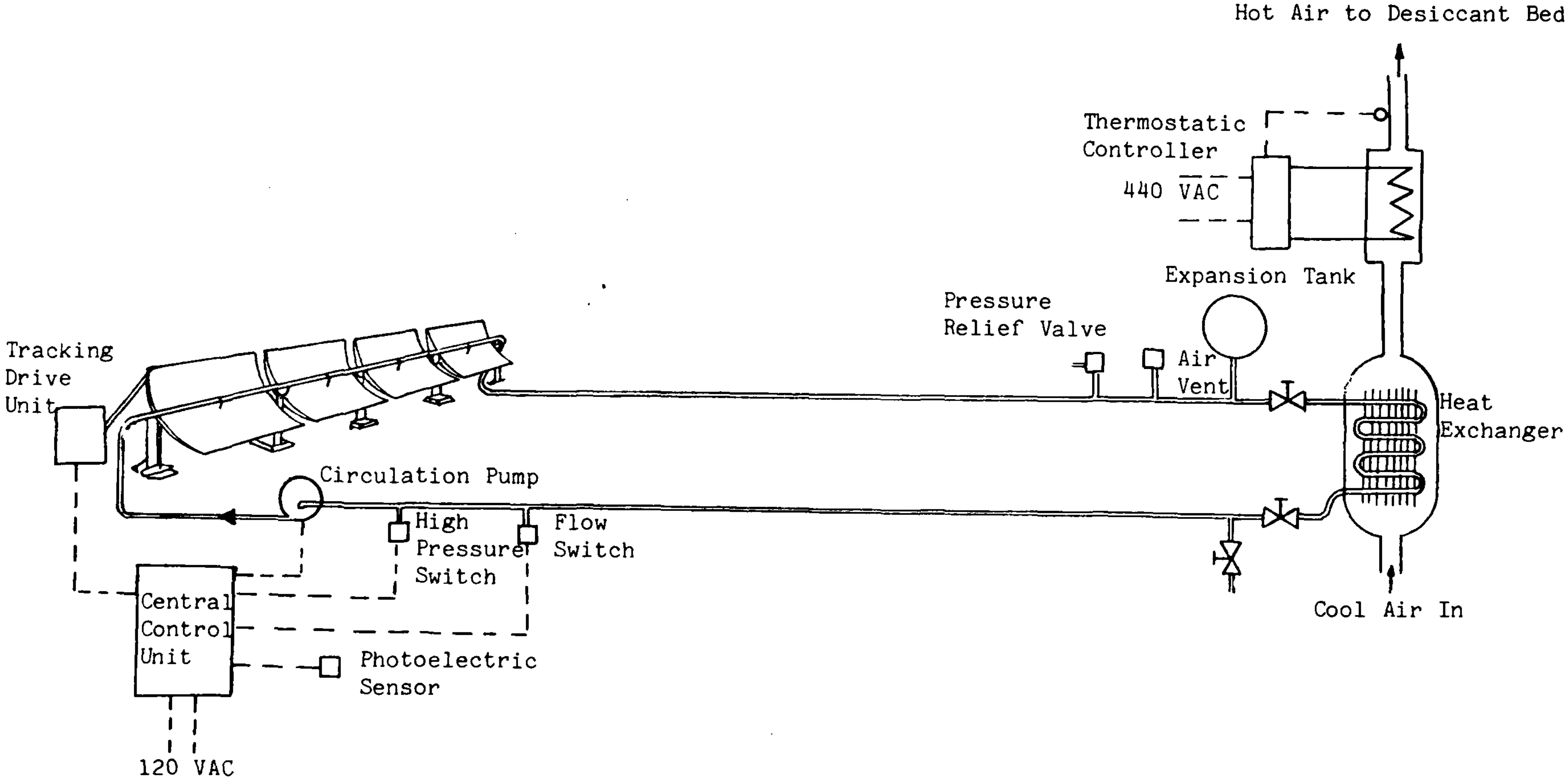

Figure 9. Schematic Diagram of Solar Thermal System.

-to-center distance of the end pylons for a four-collector array is 25.32m (83 ft.). Field piping is 1¼" I. D. schedule 40 steel pipe with butt welded joints and butt welded connections to the manufacturer supplied standard end flex hoses at both ends of the array.

The heat transfer fluid recommended is Therminol T-60 manufactured by Monsanto. Thermophysical properties for Therminol T-60 are given in Table 7. The existing reactivation cooler heat exchanger in the IAD system indicated in Figure 3 can be used as the load side heat exchanger. It is a Degree Model 19C-03.5-2 with coil dimensions of 0.5m dia. x 1.07m long with four passes on the gas side. The coil contains 23 BWQ copper tubes with 14 aluminum fins per inch. The liquid side connections are 1¼" NPT compatible with the field piping to be used. The nominal flow rate for the air is 220 scfm. The nominal flow rate for the heat transfer fluid is 10 gal/min. This liquid flow rate will result in a 20°C (35°F) rise in the fluid temperature across the collector array.

TABLE 7

Thermophysical Properties of Therminol T-60

Temp. °F	Density lbm/gal	Specific Heat BTU/lbm°F	Thermal Conductivity BTU/Hr-Ft-°F	Viscosity Centistokes
0	8.5	0.346	0.0780	65.0
200	7.9	0.445	0.0731	1.75
400	7.3	0.543	0.0681	0.62
450	7.12	0.568	0.0668	0.52

It may be feasible to mount the 25m long array on top of Building 24B which would help keep the piping length between the array and the IAD to a minimum. If structural or other considerations do not permit this location, the collectors could be ground mounted on the south side of Building 461. In this case, the total pipe run would be approximately 180m (600 ft.). This length of $1\frac{1}{4}$" pipe plus the 25m absorber will have a volumetric capacity of 43 gallons. To raise 43 gallons of Therminol T-60 from 0°F to 350°F on a clear January morning will require about 50 min. Thus, if the day remains clear, the solar system can supply all of the energy required for desiccant drying after an initial warm up period which can be accomplished by 9:30 a.m. even in the winter months.

d. Controls

In addition to the tracking controls supplied by SKI additional safety and operational controls are required. To prevent overheating and overpressurization of the collector loop, both a high pressure limit switch and a flow detection switch are recommended. Either switch would activate a collector stow signal in the event of circulation pump or pump control failure.

Since no energy storage is incorporated in the system, a differential temperature controller for the collector circulation pump is not appropriate. A photocell detector could be used to activate the circulation pump at insolation levels above a prescribed minimum of 0·6 kw/m^2. The same thermostatic on-off controller currently used on the IAD will suffice to control the electrical heating element which will function as a back-up or supplementary heat source. The drying system can still be activated manually in the morning or it could be controlled by a time clock. Available solar energy will preheat the air upstream of the electric element. Under clear sky conditions by 9:30 a.m. solar time (or earlier depending on the month) the air temperature leaving the heat exchanger will be 350°F and the electric heater will remain off unless needed due to cloudy conditions.

3. ECONOMIC ANALYSIS

The cost of components supplied by SKI is:

4 T-700 Mirror Modules @ $3,100 ea.	$12,400
1 Drive Unit	3,850
1 Central Control Unit	5,700
Crating	100
Shipping (estimated)	350
Total	$22,400

Estimated additional costs are as follows:

Ancillary Controls	$ 2,000
Piping and Insulation 600' @ $4/ft.	2,400
Installation	4,000
Total	$ 8,400
Total Installed System Cost (P)	$30,800

The average annual energy produced by the system can be determined from the information in Table 6. The total yearly energy that could be collected is $532 kwh/m^2 \times 52 m^2 =$ 27,664kwh if the system operated 365 days per year. However, the IAD system is not operated on weekends and during holidays. The system could thus be expected to operate about 250 days per year, reducing the expected energy production to about 18,950kwh annually. At the prevailing average electrical rate of $0.0525/kwh, the current annual savings is about $995.

For equal, and thus offsetting, discount rate and escalation rate, for instance 15% each, the total present worth of the energy savings over the expected 20-year lifetime of the system is

$$B = UPW\ (15,15,20Y) \times \$995$$
$$= 20 \times \$995 = \$19,900$$

First year maintenance and repair costs are assumed to be 2.5% of the initial purchase and installation cost

$$M = 0.25 \times \$30{,}800 \times UPW\ (15{,}15{,}20Y)$$
$$= 0.25 \times \$30{,}800 \times 20$$
$$= \$15{,}400.$$

Major replacement cost, R, is assumed zero over the 20-year lifetime as is the salvage value, S. The net present value of the system is thus

$$B\text{-}C = B\text{-}(P+M+R+S)$$
$$= \$19{,}900 - (\$30{,}800 + \$15{,}400)$$
$$= -\$26{,}300.$$

Again, the value of energy produced more than offsets maintenance and repair but does not recover the initial capital investment in the assumed lifetime.

SECTION VII

CONCLUSIONS

None of the renewable energy systems evaluated show economic feasibility when subjected to a cost/benefit life-cycle cost analysis. Assumptions made regarding cash flow parameters, such as escalation and discount rates and maintenance costs, are subject to a degree of uncertainty. However, even large deviations from the assumed values will not alter the basic outcome much. If maintenance and repair costs are negligible, all three systems (a) wind turbine (b) photovoltaic and (c) solar thermal still show a negative present value, never displacing sufficient electrical energy to amortize the initial investment over a 20-year lifetime. The inflation rate for purchased electricity would have to be quadruple the discount rate for even the wind turbine system (which displays the best economic potential) to produce a positive net present value.

The wind turbine system comes nearest to economic viability due to its low initial cost and good load match. This system may have merit from other than purely economic considerations. It could provide a utility independent charging capability for the D. C. Battery Supply System to maintain operation of the D. C. oil pumps and switching relays in the event of an extended power failure. The wind power system has advantages over the photovoltaic system for this application due to its much lower initial cost and potential for 24-hour operation as opposed to 8-hour per day maximum potential operation for the photovoltaic system. An additional consideration is that while no wind or solar energy system can be totally relied upon to provide emergency standby power due to the variable nature of the energy source, availability of wind energy statistically coincides with the times of highest probability of power outages, i.e., storm periods.

SECTION VIII

ENVIRONMENTAL IMPACT STUDY

Although installation of the three renewable energy systems described in this report, viz., photovoltaic system, wind turbine system and solar thermal energy system, is not warranted from economic considerations, consideration may be given to installing one or more of the systems for other reasons, for example as a back-up charging system for the D. C. Battery Supply. An environmental impact study is thus provided here in the event such an installation is contemplated.

All three renewable energy systems are environmentally benign. The photovoltaic system has no conceivable adverse environmental effects. The only conceivable adverse environmental effect attributable to a wind turbine generator system is noise. Noise was a major problem with the 200 megawatt DOE/NASA wind system installation at Boone, NC. However, due to the small size (3 kw) of the system described here, the noise level is not expected to be of any concern, if indeed it is audible at all.

The solar thermal system poses one potential environmental hazard associated with the heat transfer fluid Therminol T-60. Approximately 43 gallons of this hydrocarbon base oil would be used in the collector loop of the solar thermal system. Care must be exercised in filling and draining the system to prevent spills. Due to the small volume of oil involved, the danger to the environment posed by even a total spill is not great and such a spill could be cleaned up rather easily with no lasting environmental effects.

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APPENDIX A

SOLAR RADIATION DATA

TABLE A-1

Long-Term Average Solar Radiation Values for Dayton

DAYTON

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LATITUDE = 39.90   LONGITUDE = 84.20   ELEVATION =995.00

AZIMUTH = 0.0 DEGREES

MONTH	HORIZONTAL TOTAL	HORIZONTAL BEAM	TILT 15 DEG. TOTAL	TILT 15 DEG. BEAM	TILT 25 DEG. TOTAL	TILT 25 DEG. BEAM	TILT 35 DEG. TOTAL	TILT 35 DEG. BEAM
1	493.	325.	662.	495.	752.	588.	824.	662.
2	735.	515.	926.	708.	1021.	804.	1090.	876.
3	1042.	758.	1207.	926.	1276.	996.	1313.	1036.
4	1407.	1036.	1526.	1158.	1547.	1180.	1531.	1167.
5	1718.	1291.	1779.	1355.	1748.	1325.	1677.	1256.
6	1876.	1433.	1878.	1436.	1818.	1376.	1718.	1278.
7	1812.	1386.	1827.	1401.	1779.	1354.	1693.	1268.
8	1651.	1276.	1724.	1348.	1723.	1348.	1682.	1307.
9	1333.	1035.	1472.	1172.	1530.	1230.	1550.	1251.
10	969.	731.	1128.	887.	1223.	984.	1288.	1050.
11	559.	378.	691.	509.	775.	594.	839.	661.
12	408.	262.	553.	407.	634.	489.	699.	557.

****

MONTH	TILT 45 DEG. TOTAL	TILT 45 DEG. BEAM	TILT 55 DEG. TOTAL	TILT 55 DEG. BEAM	TILT 90 DEG. TOTAL	TILT 90 DEG. BEAM	TOTAL NORMAL TRACKING
1	875.	717.	904.	749.	822.	684.	1035.
2	1132.	921.	1145.	938.	968.	778.	1369.
3	1318.	1044.	1291.	1020.	962.	706.	1676.
4	1479.	1119.	1393.	1037.	872.	532.	2037.
5	1570.	1151.	1430.	1013.	764.	359.	2367.
6	1583.	1144.	1418.	979.	701.	269.	2511.
7	1570.	1147.	1417.	994.	724.	305.	2432.
8	1602.	1227.	1486.	1111.	861.	488.	2298.
9	1532.	1234.	1477.	1179.	1022.	726.	2018.
10	1321.	1085.	1320.	1087.	1064.	842.	1625.
11	883.	709.	965.	734.	862.	656.	1043.
12	747.	668.	.775.	640.	718.	599.	877.

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UNITS ARE BTU PER SQ.FT. PER DAY (MONTHLY AVG.)
FOR K-JOULES PER SQ.METER PER DAY MULTIPLY BY 11.35

TABLE A-1 Cont.

DAYTON

LATITUDE = 39.90 LONGITUDE = 84.20 ELEVATION =995.00

AZIMUTH = 30.0 DEGREES

MONTH	HORIZONTAL		TILT 15 DEG.		TILT 25 DEG.		TILT 35 DEG.	
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
1	493.	325.	638.	471.	714.	549.	772.	610.
2	735.	515.	899.	681.	976.	760.	1030.	816.
3	1042.	758.	1183.	952.	1237.	957.	1262.	985.
4	1407.	1036.	1509.	1141.	1521.	1155.	1562.	1138.
5	1718.	1291.	1771.	1346.	1739.	1316.	1673.	1252.
6	1876.	1433.	1875.	1433.	1818.	1377.	1728.	1287.
7	1812.	1386.	1821.	1396.	1776.	1351.	1697.	1272.
8	1651.	1276.	1709.	1334.	1703.	1328.	1662.	1287.
9	1333.	1035.	1447.	1147.	1491.	1191.	1500.	1201.
10	969.	731.	1099.	858.	1176.	936.	1225.	987.
11	559.	378.	669.	486.	738.	557.	790.	611.
12	408.	262.	532.	386.	600.	456.	653.	511.

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MONTH	TILT 45 DEG.		TILT 55 DEG.		TILT 90 DEG.		TOTAL NORMAL
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TRACKING
1	811.	652.	829.	674.	731.	593.	1035.
2	1058.	847.	1066.	853.	869.	679.	1369.
3	1258.	984.	1225.	954.	908.	652.	1676.
4	1451.	1090.	1370.	1014.	910.	570.	2037.
5	1576.	1157.	1452.	1035.	876.	471.	2367.
6	1607.	1168.	1461.	1023.	838.	466.	2511.
7	1587.	1163.	1451.	1028.	851.	432.	2432.
8	1587.	1212.	1481.	1106.	938.	565.	2298.
9	1476.	1177.	1419.	1120.	1000.	703.	2018.
10	1243.	1008.	1232.	999.	968.	745.	1625.
11	822.	647.	834.	663.	715.	563.	1043.
12	690.	551.	709.	574.	638.	518.	877.

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UNITS ARE BTU PER SQ.FT. PER DAY (MONTHLY AVG.)
FOR K-JOULES PER SQ.METER PER DAY MULTIPLY BY 11.35

TABLE A-1 Cont.

DAYTON

LATITUDE = 39.90 LONGITUDE = 84.20 ELEVATION =995.00

AZIMUTH = 45.0 DEGREES

MONTH	HORIZONTAL		TILT 15 DEG.		TILT 25 DEG.		TILT 35 DEG.	
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
1	493.	325.	610.	443.	668.	503.	710.	548.
2	735.	515.	867.	649.	925.	709.	963.	749.
3	1042.	758.	1155.	874.	1193.	913.	1206.	929.
4	1407.	1036.	1489.	1121.	1492.	1126.	1468.	1104.
5	1718.	1291.	1760.	1336.	1726.	1303.	1663.	1241.
6	1876.	1433.	1870.	1428.	1815.	1374.	1731.	1298.
7	1812.	1386.	1814.	1389.	1769.	1343.	1694.	1270.
8	1651.	1276.	1692.	1316.	1679.	1303.	1635.	1260.
9	1333.	1035.	1418.	1118.	1447.	1147.	1446.	1147.
10	969.	731.	1064.	824.	1122.	882.	1154.	916.
11	559.	378.	642.	459.	695.	514.	732.	553.
12	408.	262.	508.	362.	560.	415.	599.	457.

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MONTH	TILT 45 DEG.		TILT 55 DEG.		TILT 90 DEG.		TOTAL NORMAL
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TRACKING
1	735.	576.	743.	588.	631.	493.	1035.
2	978.	767.	970.	763.	778.	588.	1369.
3	1194.	920.	1158.	887.	863.	607.	1676.
4	1416.	1056.	1340.	983.	923.	583.	2037.
5	1573.	1154.	1459.	1043.	943.	537.	2367.
6	1621.	1181.	1489.	1051.	931.	498.	2511.
7	1593.	1169.	1469.	1046.	932.	513.	2432.
8	1563.	1188.	1465.	1090.	977.	604.	2298.
9	1416.	1117.	1358.	1060.	975.	679.	2018.
10	1160.	924.	1140.	907.	885.	663.	1625.
11	751.	577.	753.	583.	626.	474.	1043.
12	623.	484.	632.	497.	547.	427.	877.

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UNITS ARE BTU PER SQ.FT. PER DAY (MONTHLY AVG.)
FOR K-JOULES PER SQ.METER PER DAY MULTIPLY BY 11.35

TABLE A-1 Cont.

DAYTON

LATITUDE = 39.90 LONGITUDE = 84.20 ELEVATION =995.00

AZIMUTH = 60.0 DEGREES

MONTH	HORIZONTAL		TILT 15 DEG.		TILT 25 DEG.		TILT 35 DEG.	
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
1	493.	325.	574.	407.	610.	445.	634.	472.
2	735.	515.	826.	608.	862.	645.	880.	666.
3	1042.	758.	1118.	837.	1137.	858.	1136.	859.
4	1407.	1036.	1462.	1094.	1453.	1087.	1421.	1057.
5	1718.	1291.	1746.	1321.	1706.	1283.	1643.	1222.
6	1876.	1433.	1863.	1421.	1807.	1366.	1727.	1286.
7	1812.	1386.	1804.	1379.	1756.	1331.	1683.	1259.
8	1651.	1276.	1668.	1293.	1645.	1270.	1596.	1221.
9	1333.	1035.	1381.	1081.	1390.	1091.	1376.	1077.
10	969.	731.	1020.	780.	1053.	813.	1066.	828.
11	559.	378.	608.	425.	640.	459.	660.	482.
12	408.	262.	476.	330.	509.	364.	531.	389.

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MONTH	TILT 45 DEG.		TILT 55 DEG.		TILT 90 DEG.		TOTAL NORMAL
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TRACKING
1	644.	485.	640.	485.	526.	388.	1035.
2	881.	670.	864.	657.	681.	491.	1369.
3	1115.	841.	1075.	804.	804.	548.	1676.
4	1368.	1007.	1294.	937.	917.	577.	2037.
5	1558.	1138.	1453.	1036.	985.	580.	2367.
6	1625.	1185.	1504.	1066.	998.	566.	2511.
7	1588.	1164.	1475.	1052.	989.	570.	2432.
8	1525.	1150.	1432.	1058.	992.	620.	2298.
9	1338.	1040.	1279.	981.	932.	636.	2018.
10	1058.	822.	1030.	797.	793.	570.	1625.
11	666.	491.	658.	488.	532.	380.	1043.
12	542.	403.	541.	406.	450.	330.	877.

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UNITS ARE BTU PER SQ.FT. PER DAY (MONTHLY AVG.)
FOR K-JOULES PER SQ.METER PER DAY MULTIPLY BY 11.35

TABLE A-1 Cont.

DAYTON

LATITUDE = 39.90   LONGITUDE = 84.20   ELEVATION =995.00

AZIMUTH = 90.0 DEGREES

MONTH	HORIZONTAL TOTAL	HORIZONTAL BEAM	TILT 15 DEG. TOTAL	TILT 15 DEG. BEAM	TILT 25 DEG. TOTAL	TILT 25 DEG. BEAM	TILT 35 DEG. TOTAL	TILT 35 DEG. BEAM
1	493.	325.	488.	321.	477.	312.	464.	302.
2	735.	515.	729.	511.	711.	495.	689.	475.
3	1042.	758.	1030.	749.	1000.	721.	964.	686.
4	1407.	1036.	1396.	1028.	1351.	984.	1293.	929.
5	1718.	1291.	1708.	1284.	1647.	1224.	1569.	1148.
6	1876.	1433.	1843.	1401.	1775.	1333.	1687.	1246.
7	1812.	1386.	1776.	1351.	1712.	1286.	1628.	1204.
8	1651.	1276.	1610.	1235.	1554.	1178.	1482.	1107.
9	1333.	1035.	1289.	990.	1248.	949.	1197.	899.
10	969.	731.	915.	674.	890.	650.	859.	621.
11	559.	378.	527.	344.	514.	333.	499.	321.
12	408.	262.	401.	255.	392.	248.	382.	240.

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MONTH	TILT 45 DEG. TOTAL	TILT 45 DEG. BEAM	TILT 55 DEG. TOTAL	TILT 55 DEG. BEAM	TILT 90 DEG. TOTAL	TILT 90 DEG. BEAM	TOTAL NORMAL TRACKING
1	448.	289.	428.	273.	328.	190.	1035.
2	662.	451.	630.	423.	476.	286.	1369.
3	920.	645.	869.	598.	644.	387.	1676.
4	1225.	865.	1149.	792.	829.	489.	2037.
5	1479.	1060.	1378.	962.	975.	570.	2367.
6	1585.	1146.	1473.	1035.	1033.	601.	2511.
7	1532.	1108.	1425.	1002.	1003.	585.	2432.
8	1399.	1025.	1307.	933.	933.	561.	2298.
9	1138.	839.	1070.	772.	781.	485.	2018.
10	822.	586.	779.	545.	582.	359.	1625.
11	481.	306.	458.	288.	350.	198.	1043.
12	369.	230.	353.	217.	272.	153.	877.

****

UNITS ARE BTU PER SQ.FT. PER DAY (MONTHLY AVG.)
FOR K-JOULES PER SQ.METER PER DAY MULTIPLY BY 11.35

TABLE A-2

Clear Day Solar Radiation Values on Tracing and South Facing Surfaces for Dayton

DAYTON

LATITUDE = 39.90 LONGITUDE = 84.20 ELEVATION =995.00

AZIMUTH = 0.0 DEGREES

MONTH	HORIZONTAL		TILT 15 DEG.		TILT 25 DEG.		TILT 35 DEG.	
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
1	916.	792.	1316.	1192.	1541.	1415.	1723.	1594.
2	1273.	1123.	1667.	1516.	1876.	1721.	2035.	1875.
3	1735.	1538.	2051.	1851.	2196.	1991.	2282.	2070.
4	2219.	1935.	2403.	2116.	2449.	2156.	2432.	2132.
5	2511.	2143.	2563.	2192.	2519.	2144.	2415.	2032.
6	2579.	2170.	2566.	2154.	2481.	2065.	2339.	1917.
7	2469.	2066.	2482.	2076.	2416.	2007.	2294.	1879.
8	2216.	1866.	2329.	1976.	2332.	1976.	2277.	1916.
9	1839.	1574.	2077.	1810.	2170.	1900.	2208.	1932.
10	1426.	1234.	1775.	1580.	1950.	1753.	2074.	1872.
11	1000.	860.	1382.	1241.	1592.	1449.	1760.	1613.
12	786.	673.	1163.	1049.	1377.	1262.	1554.	1436.

****

MONTH	TILT 40 DEG.		TILT 55 DEG.		TILT 90 DEG.		TOTAL NORMAL
	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TRACKING
1	1797.	1666.	1942.	1804.	1804.	1648.	2273.
2	2093.	1930.	2181.	2008.	1871.	1665.	2668.
3	2302.	2086.	2271.	2039.	1691.	1412.	3038.
4	2401.	2096.	2216.	1894.	1346.	972.	3377.
5	2342.	1954.	2043.	1640.	1031.	581.	3539.
6	2249.	1822.	1910.	1469.	886.	403.	3534.
7	2214.	1795.	1904.	1472.	923.	452.	3398.
8	2229.	1864.	2007.	1629.	1131.	715.	3190.
9	2205.	1926.	2112.	1820.	1451.	1122.	2941.
10	2115.	1910.	2152.	1937.	1746.	1501.	2700.
11	1826.	1677.	1946.	1792.	1760.	1585.	2301.
12	1626.	1507.	1774.	1650.	1682.	1543.	2057.

****

UNITS ARE BTU PER SQ.FT. PER DAY (MONTHLY AVG.)
FOR K-JOULES PER SQ.METER PER DAY MULTIPLY BY 11.36

TABLE A-3

Hourly Average Day Solar Radiation Values For Dayton
(For Fixed Tilt Angle = 40°, Azimuth Angle = 0°
and Tracking Surfaces)

Units are kwh/m^2

MONTH = 1

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.406	0.488	0.441	0.519
+OR- 2	0.292	0.369	0.340	0.412
+OR- 3	0.278	0.336	0.381	0.436
+OR- 4	0.118	0.152	0.214	0.243
+OR- 5	0.012	0.016	0.030	0.033

MONTH = 2

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.485	0.580	0.506	0.599
+OR- 2	0.348	0.441	0.394	0.484
+OR- 3	0.264	0.341	0.340	0.412
+OR- 4	0.226	0.276	0.370	0.417
+OR- 5	0.081	0.101	0.202	0.219
+OR- 6	0.000	0.000	0.000	0.000

MONTH = 3

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.556	0.662	0.564	0.670
+OR- 2	0.404	0.512	0.443	0.550
+OR- 3	0.307	0.401	0.385	0.477
+OR- 4	0.274	0.343	0.445	0.512
+OR- 5	0.137	0.181	0.360	0.401
+OR- 6	0.010	0.017	0.056	0.062

TABLE A-3 Cont.

MONTH = 4

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.482	0.617	0.496	0.632
+OR- 2	0.366	0.500	0.405	0.539
+OR- 3	0.436	0.546	0.557	0.667
+OR- 4	0.254	0.351	0.441	0.536
+OR- 5	0.138	0.208	0.382	0.448
+OR- 6	0.029	0.063	0.224	0.254
+OR- 7	0.000	0.001	0.006	0.007

MONTH = 5

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.491	0.633	0.524	0.666
+OR- 2	0.455	0.591	0.518	0.654
+OR- 3	0.456	0.576	0.609	0.729
+OR- 4	0.264	0.373	0.470	0.578
+OR- 5	0.156	0.243	0.447	0.531
+OR- 6	0.041	0.098	0.328	0.379
+OR- 7	0.000	0.016	0.110	0.123
+OR- 8	0.000	0.000	0.000	0.000

MONTH = 6

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.557	0.694	0.613	0.748
+OR- 2	0.560	0.691	0.668	0.797
+OR- 3	0.352	0.480	0.495	0.624
+OR- 4	0.264	0.377	0.475	0.586
+OR- 5	0.182	0.275	0.513	0.605
+OR- 6	0.046	0.117	0.441	0.507
+OR- 7	0.000	0.026	0.137	0.158
+OR- 8	0.000	0.000	0.000	0.000

TABLE A-3 Cont.

MONTH = 7

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.554	0.688	0.602	0.735
+OR- 2	0.535	0.665	0.630	0.758
+OR- 3	0.314	0.439	0.426	0.551
+OR- 4	0.314	0.422	0.551	0.659
+OR- 5	0.174	0.265	0.496	0.585
+OR- 6	0.042	0.107	0.375	0.435
+OR- 7	0.000	0.022	0.130	0.149
+OR- 8	0.000	0.000	0.000	0.000

MONTH = 8

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.598	0.724	0.623	0.748
+OR- 2	0.581	0.702	0.654	0.774
+OR- 3	0.416	0.531	0.556	0.672
+OR- 4	0.262	0.362	0.452	0.551
+OR- 5	0.184	0.264	0.493	0.570
+OR- 6	0.041	0.091	0.331	0.376
+OR- 7	0.000	0.006	0.035	0.040

MONTH = 9

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.548	0.661	0.554	0.668
+OR- 2	0.585	0.689	0.636	0.740
+OR- 3	0.422	0.519	0.539	0.637
+OR- 4	0.293	0.374	0.483	0.563
+OR- 5	0.170	0.228	0.442	0.497
+OR- 6	0.026	0.047	0.164	0.182
+OR- 7	0.000	0.000	0.000	0.000

TABLE A-3 Cont.

MONTH = 10

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.502	0.605	0.514	0.616
+OR- 2	0.544	0.635	0.598	0.690
+OR- 3	0.371	0.454	0.479	0.561
+OR- 4	0.293	0.355	0.492	0.552
+OR- 5	0.100	0.133	0.265	0.294
+OR- 6	0.005	0.007	0.022	0.024

MONTH = 11

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.346	0.434	0.369	0.453
+OR- 2	0.314	0.393	0.358	0.433
+OR- 3	0.282	0.345	0.376	0.435
+OR- 4	0.130	0.171	0.226	0.260
+OR- 5	0.039	0.048	0.092	0.099

MONTH = 12

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.294	0.369	0.324	0.394
+OR- 2	0.249	0.316	0.292	0.354
+OR- 3	0.207	0.257	0.276	0.322
+OR- 4	0.135	0.161	0.233	0.256
+OR- 5	0.008	0.010	0.018	0.020

TABLE A-4

Hourly Clear Day Solar Radiation Values for Dayton
(For Fixed Tilt Angle = 40°, Azimuth Angle = 0°
and Tracking Surfaces)

Units are kwh/m^2

MONTH = 1

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.859	0.918	0.931	0.998
+OR- 2	0.772	0.828	0.899	0.962
+OR- 3	0.602	0.651	0.816	0.869
+OR- 4	0.340	0.375	0.597	0.631
+OR- 5	0.043	0.048	0.101	0.106

MONTH = 2

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.930	0.996	0.966	1.038
+OR- 2	0.846	0.909	0.944	1.014
+OR- 3	0.684	0.741	0.889	0.952
+OR- 4	0.447	0.494	0.758	0.808
+OR- 5	0.152	0.174	0.383	0.403
+OR- 6	0.000	0.000	0.000	0.000

MONTH = 3

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.951	1.028	0.963	1.041
+OR- 2	0.871	0.945	0.947	1.025
+OR- 3	0.718	0.788	0.910	0.985
+OR- 4	0.500	0.561	0.830	0.896
+OR- 5	0.246	0.291	0.645	0.690
+OR- 6	0.029	0.039	0.154	0.163

TABLE A-4 Cont.

MONTH = 4

HOURS FROM NOON	TILT40.DEGREES BEAM	TOTAL	TRACKING BEAM	TOTAL
+OR- 1	0.927	1.026	0.950	1.045
+OR- 2	0.851	0.948	0.938	1.033
+OR- 3	0.708	0.799	0.909	1.002
+OR- 4	0.508	0.591	0.853	0.939
+OR- 5	0.273	0.342	0.736	0.806
+OR- 6	0.063	0.103	0.455	0.492
+OR- 7	0.000	0.002	0.025	0.026

MONTH = 5

HOURS FROM NOON	TILT40.DEGREES BEAM	TOTAL	TRACKING BEAM	TOTAL
+OR- 1	0.853	0.970	0.911	1.021
+OR- 2	0.785	0.899	0.900	1.010
+OR- 3	0.654	0.764	0.876	0.985
+OR- 4	0.474	0.575	0.831	0.934
+OR- 5	0.265	0.353	0.746	0.835
+OR- 6	0.069	0.134	0.569	0.630
+OR- 7	0.000	0.019	0.174	0.190
+OR- 8	0.000	0.000	0.000	0.000

MONTH = 6

HOURS FROM NOON	TILT40.DEGREES BEAM	TOTAL	TRACKING BEAM	TOTAL
+OR- 1	0.791	0.915	0.871	0.987
+OR- 2	0.728	0.851	0.861	0.978
+OR- 3	0.606	0.723	0.838	0.954
+OR- 4	0.442	0.551	0.798	0.909
+OR- 5	0.250	0.347	0.726	0.823
+OR- 6	0.066	0.142	0.586	0.658
+OR- 7	0.000	0.033	0.266	0.295
+OR- 8	0.000	0.000	0.003	0.003

TABLE A-4 Cont.

MONTH = 7

HOURS FROM NOON	TILT40.DEGREES BEAM	TILT40.DEGREES TOTAL	TRACKING BEAM	TRACKING TOTAL
+OR- 1	0.781	0.906	0.850	0.968
+OR- 2	0.719	0.841	0.840	0.958
+OR- 3	0.600	0.717	0.818	0.934
+OR- 4	0.432	0.541	0.775	0.885
+OR- 5	0.244	0.340	0.700	0.796
+OR- 6	0.065	0.138	0.550	0.619
+OR- 7	0.000	0.028	0.219	0.243
+OR- 8	0.000	0.000	0.000	0.000

MONTH = 8

HOURS FROM NOON	TILT40.DEGREES BEAM	TILT40.DEGREES TOTAL	TRACKING BEAM	TRACKING TOTAL
+OR- 1	0.820	0.937	0.857	0.968
+OR- 2	0.755	0.868	0.845	0.957
+OR- 3	0.625	0.733	0.819	0.927
+OR- 4	0.448	0.548	0.768	0.870
+OR- 5	0.247	0.331	0.673	0.758
+OR- 6	0.058	0.114	0.467	0.513
+OR- 7	0.000	0.008	0.072	0.079

MONTH = 9

HOURS FROM NOON	TILT40.DEGREES BEAM	TILT40.DEGREES TOTAL	TRACKING BEAM	TRACKING TOTAL
+OR- 1	0.870	0.967	0.881	0.978
+OR- 2	0.797	0.892	0.867	0.963
+OR- 3	0.657	0.746	0.834	0.926
+OR- 4	0.462	0.542	0.767	0.849
+OR- 5	0.236	0.299	0.623	0.685
+OR- 6	0.042	0.067	0.256	0.277
+OR- 7	0.000	0.000	0.000	0.000

TABLE A-4 Cont.

MONTH = 10

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.903	0.983	0.923	1.006
+OR- 2	0.824	0.900	0.903	0.985
+OR- 3	0.669	0.740	0.856	0.931
+OR- 4	0.451	0.510	0.752	0.814
+OR- 5	0.188	0.225	0.485	0.520
+OR- 6	0.007	0.010	0.034	0.036

MONTH = 11

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.849	0.914	0.904	0.975
+OR- 2	0.767	0.829	0.876	0.944
+OR- 3	0.605	0.660	0.806	0.865
+OR- 4	0.368	0.409	0.635	0.676
+OR- 5	0.073	0.084	0.176	0.186

MONTH = 12

HOURS FROM NOON	TILT40.DEGREES		TRACKING	
	BEAM	TOTAL	BEAM	TOTAL
+OR- 1	0.800	0.856	0.879	0.942
+OR- 2	0.716	0.769	0.845	0.904
+OR- 3	0.549	0.594	0.754	0.802
+OR- 4	0.288	0.317	0.508	0.537
+OR- 5	0.022	0.024	0.050	0.053

TABLE A-5

Wind Velocity Distributions For Dayton Municipal Airport
(From Reference 5)

January A. ALL WEATHER

WIND DIR	WIND SPEED (KNOTS) 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
N	.3	1.3	1.3	1.0	.2					4.1	8.4
NNE	.2	1.5	1.0	.3	.1	.1				3.2	7.6
NE	.1	.8	.8	.4						2.1	7.9
ENE	.1	.7	.9	.6	.0					2.3	8.2
E	.1	1.0	2.3	1.0						4.5	8.8
ESE	.2	1.1	1.4	1.3	.2					4.2	9.2
SE	.3	1.9	1.9	.9	.1					5.1	7.9
SSE	.1	1.0	1.5	.8	.2					3.6	8.9
S	.2	2.9	4.6	5.4	1.0	.1				14.1	10.4
SSW	.2	1.0	4.0	3.7	1.5	.1				10.4	11.5
SW	.2	1.2	2.1	1.7	.4					5.6	9.7
WSW	.3	1.6	2.1	3.1	.7	.1	.0			7.9	11.0
W	.3	2.8	5.1	6.9	1.0	.2		.0		16.3	10.9
WNW	.1	.9	2.9	2.6	.2	.0				6.9	10.3
NW	.0	1.1	1.9	.6	.1					3.8	8.3
NNW	.2	.7	1.6	1.0	.2					3.8	9.4
CALM	2.1									2.1	
TOT	5.2	21.6	35.4	31.3	5.9	.6	.0	.0		100.0	9.7

ALL WEATHER: ALL WIND OBSERVATIONS

February A. ALL WEATHER

WIND DIR	WIND SPEED (KNOTS) 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
N	.5	1.6	2.1	1.8	.5	.1				6.6	9.6
NNE	.0	1.1	1.3	1.2	.2	.0				3.8	9.6
NE	.1	1.2	1.0	.7						3.0	7.9
ENE	.1	.8	1.6	1.0						3.6	8.7
E	.2	1.5	2.8	1.0						5.5	8.4
ESE		.9	1.7	.9	.0					3.6	8.7
SE	.1	1.2	2.4	.9						4.6	8.4
SSE		.8	1.3	1.1	.1					3.3	9.5
S	.2	1.2	3.5	3.8	.8	.1				9.6	10.9
SSW	.1	1.2	2.7	3.7	.9	.1				8.7	11.4
SW	.1	.6	2.0	2.1	.4	.1	.0			5.3	11.2
WSW	.2	.9	2.1	3.0	1.1	.4				7.6	12.0
W	.5	2.2	4.5	6.5	1.2	.3	.0			15.3	11.2
WNW	.1	1.7	2.3	2.7	.6	.1				7.5	10.4
NW	.0	1.4	1.6	2.2	.2	.1				5.5	10.2
NNW	.1	1.3	1.7	1.6	.5	.1				5.5	10.3
CALM	1.2									1.2	
TOT	3.5	19.6	34.5	34.4	6.6	1.4	.1			100.0	10.2

ALL WEATHER: ALL WIND OBSERVATIONS

March A. ALL WEATHER

WIND DIR	WIND SPEED (KNOTS) 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
N	.3	1.6	3.0	2.1	.4	.1				7.5	9.7
NNE	.2	1.7	1.5	1.6	.1	.1				5.2	9.0
NE	.1	.8	1.9	1.4	.2					4.4	9.8
ENE	.2	1.1	1.7	.9						3.9	8.0
E	.1	1.8	2.4	.8	.1					5.1	8.0
ESE	.1	1.1	2.1	.8	.2					4.4	8.8
SE	.1	1.5	3.2	1.3						6.0	8.5
SSE	.1	1.5	1.8	.9	.1					4.4	8.4
S	.2	1.5	3.2	3.7	.8	.1				9.5	10.8
SSW	.1	.9	2.3	3.3	.7	.3				7.7	11.8
SW	.1	.8	1.2	1.8	.6	.2	.0			4.8	12.0
WSW	.1	1.2	1.7	2.0	.9	.2				6.0	11.2
W	.3	2.4	3.3	5.2	2.3	.5	.0			14.1	11.9
WNW	.0	1.7	1.9	2.6	.6					6.8	10.5
NW	.2	1.4	2.0	1.4	.2					5.2	9.2
NNW	.1	.9	1.4	1.3	.4					4.0	9.8
CALM	1.0									1.0	
TOT	3.5	21.7	34.4	31.0	7.8	1.5	.1			100.0	10.1

ALL WEATHER ALL WIND OBSERVATIONS

April A. ALL WEATHER

WIND DIR	WIND SPEED (KNOTS) 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
N	.3	.8	1.6	1.8	.5	.0				5.0	10.2
NNE	.2	1.0	1.5	1.3	.2					4.3	9.2
NE	.2	1.0	1.2	1.1	.2					3.7	9.1
ENE	.2	1.0	2.0	1.3	.0					4.4	8.7
E	.2	1.7	1.9	1.8	.1					5.7	8.9
ESE	.1	1.5	2.3	1.8	.1					5.7	8.9
SE	.2	1.6	2.4	1.0	.1					5.3	8.0
SSE	.2	1.1	2.1	1.6		.0				5.0	9.0
S	.3	1.6	4.9	5.0	1.0	.2				12.9	10.9
SSW	.1	.8	2.5	3.0	.5	.1				7.1	11.2
SW	.1	.9	1.8	2.3	.8	.1				6.1	11.3
WSW	.1	1.0	1.5	1.9	.9	.2				5.7	11.5
W	.4	1.3	2.6	3.9	1.2	.6				9.9	12.0
WNW	.2	1.2	2.0	2.4	.5	.1				6.5	10.6
NW	.3	1.3	2.2	1.9	.2	.0				6.0	9.6
NNW	.2	1.3	1.5	1.5	.2					4.7	9.4
CALM	2.3									2.3	
TOT	5.7	19.1	34.1	33.4	6.4	1.4				100.0	9.9

ALL WEATHER: ALL WIND OBSERVATIONS

May A. ALL WEATHER

WIND DIR	WIND SPEED (KNOTS) 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
N	.4	2.3	1.9	1.4	.1					6.7	8.1
NNE	.3	1.9	1.4	.8	.0					4.4	7.5
NE	.2	1.0	1.6	.4	.0					3.3	7.5
ENE	.1	1.7	1.7	.3						3.8	7.0
E	.5	2.5	2.7	.9	.1					6.7	7.5
ESE	.1	1.6	1.8	.8	.0					4.3	8.2
SE	.3	1.9	2.7	.5	.0					5.4	7.4
SSE	.2	1.7	1.5	.6	.0					4.0	7.4
S	.4	2.6	4.9	3.7	.3					11.9	9.3
SSW	.2	1.4	3.6	2.4	.7					8.3	10.0
SW	.2	2.2	2.7	2.3	.3	.1				7.8	9.4
WSW	.3	.9	2.2	1.8	.3	.0	.0			5.5	10.1
W	.3	2.8	3.7	2.8	.2	.0				9.9	9.0
WNW	.3	1.3	2.0	1.9	.2					5.7	9.4
NW	.1	1.4	2.0	1.0		.0				4.6	8.5
NNW	.3	2.1	2.3	.8	.0					5.6	7.6
CALM	2.7									2.7	
TOT	6.9	29.2	38.9	22.3	2.5	.2	.0			100.0	8.4

ALL WEATHER ALL WIND OBSERVATIONS

June A. ALL WEATHER

WIND DIR	WIND SPEED (KNOTS) 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
N	.5	1.5	1.9	1.5						5.4	8.3
NNE	.3	1.3	1.7	.8	.1					4.2	7.9
NE	.2	1.3	1.9	.6	.0					4.5	7.8
ENE	.2	1.4	1.8	.8						4.2	7.7
E	.2	1.7	1.4	.4						3.8	7.0
ESE	.4	1.7	1.0	.2						3.3	6.2
SE	.3	2.5	.8	.1						3.7	5.7
SSE	.4	2.5	1.8	.5						5.3	6.8
S	.3	4.4	6.3	2.9	.2					14.0	8.3
SSW	.3	3.3	5.5	3.3	.5					12.7	8.9
SW	.4	3.1	4.3	3.0	.2					11.1	8.8
WSW	.5	1.9	2.2	1.9	.3	.0				6.7	9.0
W	.6	3.0	2.2	1.3		.0				7.4	7.7
WNW	.3	1.4	1.3	.6	.1					3.6	7.9
NW	.2	.8	1.7	.7	.1					3.5	8.6
NNW	.3	1.7	.8	.5	.0					3.3	7.4
CALM	4.0									4.0	
TOT	9.1	33.5	36.5	19.4	1.6	.1				100.0	7.7

ALL WEATHER ALL WIND OBSERVATIONS

TABLE A-5 Cont.

July A. ALL WEATHER

WIND DIR	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
	WIND SPEED (KNOTS)										
N	.4	2.7	2.2	.8	.1					6.2	7.1
NNE	.3	1.6	1.5	.3						3.7	7.0
NE	.2	1.5	1.9	.2						3.8	7.0
ENE	.4	2.1	1.9	.3						4.8	6.6
E	.3	2.0	2.1	.2						4.7	6.6
ESE	.4	1.8	.9	.0						3.1	5.9
SE	.4	2.5	.9	.0						3.8	5.6
SSE	.4	2.4	1.0	.2						4.2	5.9
S	.9	4.3	4.1	1.0	.0					10.3	7.0
SSW	.2	3.3	4.0	2.0	.1					9.6	8.2
SW	.4	3.9	3.6	1.3	.1					9.3	7.5
WSW	.5	3.5	3.5	2.1						9.6	7.8
W	.7	3.9	3.1	.9	.1					8.8	6.9
WNW	.2	2.1	2.1	.6						5.0	7.3
NW	.3	1.8	1.8	.4	.1					4.4	7.4
NNW	.4	2.1	1.7	.7	.0	.0				5.0	7.2
CALM	3.7									3.7	
TOT	10.2	41.4	36.4	11.3	.6	.0				100.0	6.8

ALL WEATHER ALL WIND OBSERVATIONS

August A. ALL WEATHER

WIND DIR	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
	WIND SPEED (KNOTS)										
N	1.0	3.3	2.1	.6						7.0	6.2
NNE	.5	1.7	1.8	.5						4.4	7.0
NE	.2	1.9	1.2	.1						3.4	6.4
ENE	.4	2.0	1.0	.2	.0					3.7	6.0
E	.4	2.7	1.7	.3	.1	.0				5.3	6.7
ESE	.3	1.7	.6	.2						2.8	5.8
SE	.3	2.4	1.1	.0						3.9	5.9
SSE	.4	2.3	1.3	.1						4.1	5.9
S	.5	3.7	4.2	.8						9.2	7.1
SSW	.4	3.0	4.2	1.3	.1					9.0	7.7
SW	.7	3.3	3.5	1.6	.2					9.3	7.6
WSW	.4	3.8	2.6	1.3	.2					8.2	7.4
W	.9	3.8	2.8	1.5		.0				9.1	7.3
WNW	.3	1.5	1.9	.7	.0					4.4	7.6
NW	.6	2.1	1.7	.4						4.9	6.5
NNW	.4	2.7	1.9	.5	.1					5.5	6.7
CALM	5.9									5.9	
TOT	13.9	41.7	33.5	10.2	.7	.1				100.0	6.5

ALL WEATHER ALL WIND OBSERVATIONS

September A. ALL WEATHER

WIND DIR	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
	WIND SPEED (KNOTS)										
N	.8	2.8	1.8	1.1	.1					6.6	7.2
NNE	.7	2.1	1.2	.7	.0					4.7	6.8
NE	.5	2.1	1.4	.5	.1					4.6	7.0
ENE	.3	2.5	1.7	.5	.0					5.1	6.9
E	.4	3.2	3.0	.5						7.0	6.8
ESE	.5	2.2	1.6	.2						4.5	6.3
SE	.3	4.1	1.8	.5						6.5	6.4
SSE	.5	3.2	1.9	.5						6.1	6.3
S	.7	4.0	5.8	1.9	.1	.0				12.6	7.8
SSW	.2	3.0	4.6	2.0	.1					9.9	8.2
SW	.3	2.5	2.1	1.3	.1					6.3	8.0
WSW	.2	1.6	1.0	.8	.0					3.6	7.8
W	.4	2.5	1.8	1.2	.1					6.0	7.6
WNW	.2	1.5	.9	.7	.1					3.3	7.7
NW	.4	1.3	1.9	1.0						4.5	7.9
NNW	.3	2.2	1.0	.8						4.4	7.1
CALM	4.3									4.3	
TOT	10.8	40.6	33.6	14.1	.8	.0				100.0	7.0

ALL WEATHER ALL WIND OBSERVATIONS

October A. ALL WEATHER

WIND DIR	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
	WIND SPEED (KNOTS)										
N	.4	1.3	1.3	1.1						4.0	8.2
NNE	.2	1.2	.6	.0						2.1	5.8
NE	.1	.8	.6	.1						1.7	6.3
ENE	.2	1.0	.7	.0						1.9	6.0
E	.6	2.3	2.1	.4						5.4	6.4
ESE	.6	3.4	2.2	.2	.0					6.5	6.2
SE	.4	4.3	3.3	.3	.0					8.3	6.7
SSE	.3	2.8	2.5	.6	.1					6.3	7.0
S	.4	4.7	6.5	3.8	.5					15.8	8.8
SSW	.4	1.7	4.0	3.2	.2					9.6	9.4
SW	.4	1.8	2.1	.9	.0					5.2	7.7
WSW	.3	1.9	1.6	1.0	.5					5.3	8.6
W	.5	3.2	3.8	2.9	.4	.0				10.8	8.9
WNW	.2	1.3	2.0	1.7						5.1	9.0
NW	.3	1.1	1.4	.8	.1					3.7	8.5
NNW	.3	1.7	1.7	.8						4.5	7.5
CALM	3.8									3.8	
TOT	9.3	34.6	36.3	17.9	1.9	.0				100.0	7.6

ALL WEATHER ALL WIND OBSERVATIONS

November A. ALL WEATHER

WIND DIR	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
	WIND SPEED (KNOTS)										
N	.5	2.0	1.5	1.0	.3					5.3	8.1
NNE	.3	.9	.7	.2						2.0	6.3
NE	.1	.5	.3	.3		.0				1.2	8.0
ENE	.1	1.2	.8	.3	.0					2.4	7.2
E	.2	1.4	1.9	.8						4.3	8.2
ESE	.1	1.3	1.0	.7	.0					3.2	8.2
SE	.1	2.0	3.0	.6						5.8	7.6
SSE	.2	1.6	1.7	.8	.1					4.4	8.2
S	.3	2.3	5.1	6.0	.6	.0				14.3	10.3
SSW	.2	1.3	3.5	4.8	.5					10.3	10.9
SW	.3	1.3	2.2	2.1	.5	.1				6.5	10.1
WSW	.3	1.6	2.3	2.5	.8	.1				7.5	10.5
W	.3	3.4	4.1	5.6	.7	.1				14.3	10.1
WNW	.3	1.4	2.5	3.2	.4					7.8	10.2
NW	.3	1.0	1.5	1.3	.0					4.1	9.0
NNW	.2	1.2	1.3	1.0	.1	.0				3.9	8.8
CALM	2.7									2.7	
TOT	6.1	24.5	33.6	31.3	4.0	.5				100.0	9.2

ALL WEATHER ALL WIND OBSERVATIONS

December A ALL WEATHER

WIND DIR	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	OVER 40	TOT	AVG SPEED
	WIND SPEED (KNOTS)										
N	.2	1.3	1.9	1.8	.2					5.9	9.4
NNE	.5	.8	1.1	.2						2.7	6.7
NE	.3	.8	.8	.2						2.3	6.8
ENE	.2	1.0	.8	.2						2.2	6.7
E	.2	1.7	2.6	1.8						6.9	8.7
ESE	.2	1.3	2.6	1.1	.0					5.2	8.5
SE	.3	1.7	3.1	1.5	.0					6.9	8.3
SSE	.2	1.0	1.8	1.2	.2					4.4	9.4
S	.2	2.3	4.6	5.2	1.3	.0				13.4	10.5
SSW	.1	.9	3.2	3.4	.8	.1	.0			8.4	11.2
SW	.1	.9	1.8	1.8	.6	.2				5.4	11.3
WSW	.4	1.0	1.5	2.7	.7	.1	.1			6.5	11.4
W	.3	2.2	4.2	5.4	1.1	.2	.0			13.4	10.9
WNW	.0	1.3	2.3	3.3	.3					7.2	10.6
NW	.2	1.2	1.5	1.4	.1	.0				4.6	9.2
NNW	.1	.7	1.5	1.3	.2					3.8	9.8
CALM	2.1									2.1	
TOT	5.7	20.1	34.4	32.6	5.5	.6	.2			100.0	9.7

ALL WEATHER ALL WIND OBSERVATIONS

APPENDIX B

OUTPUT POWER CHARACTERISTICS OF FIVE WIND TURBINES FOR WRIGHT-PATTERSON AIR FORCE BASE, OHIO

1. MACHINE CHARACTERISTICS AND OUTPUT

The curves shown in Figures 1 and 2 indicate the power resource at Wright-Patterson Air Force Base. To assess the portion of this wind power resource that is recoverable, it is necessary to add to the analysis the wind turbine input/output characteristics. Manufacturers information was obtained on 16 wind machines. Five machines with power ratings of 4.1 kw, 10 kw, 25 kw, 100 kw and 225 kw were selected to make an initial assessment. The output performance curves for these machines are included at the end of this Appendix. A summary sheet of the pertinent characteristics for the five machines is given below in Table B-1.

The average expected output power which will be available from these machines, at the hour of the day it is expected, is shown in Figure B-1. Maximum power can be seen to occur during the daylight hours between 0700 and 1900 hours. Plots of average expected machine monthly power as a function of the month in which it occurs are presented in Figure B-2. These curves show that maximum wind power occurs from November through April, with minimum power from May through October. Some of the highlights of the information contained in these curves is presented in Table B-2 to facilitate easier comparisons.

Perhaps the most interesting conclusion which might be drawn from this data is that a machine's power rating gives only an indication of what the maximum power generated by the machine will be. The average power which can be expected to be generated by a given machine, since it is dependent on the existing wind resource, is only from 5% to 10% of its maximum power rating.

TABLE B-1

Design Parameters for Five Wind Turbines

Mfg.	Aerowatt	Millville	Jay Carter	Mehrkam	Mehrkam
Model	4100 FP 7G	103-IND	Mod. 25	4-100	4-225
Rated Output	4.1 Kw	10 Kw	25 Kw	100 Kw	225 Kw
Rated Speed	16 mph	25 mph	25 mph	28 mph	28 mph
Cut In	4.5 mph	9 mph	7.5 mph	7 mph	7 mph
Cut Out		60 mph	125 mph	40 mph	40 mph
Rotor Diameter	30.7 ft.	24.3 ft.	32 ft.	N/A	N/A
Axis	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal
Output	48/120VDC	240/VAC	220/440 VAC	3Ø, AC	3Ø, AC
Base Price	$42,758	$10,750	$18,000	$80,000	$160,000
Tower	Not incl.	Not incl.	Incl.	Incl.	Incl.

TABLE B-2

Performance Summary of Five Wind Turbines for Wright-Patterson Air Force Base

Name	Aerowatt	Millville	Carter	Mehrkam	Mehrkam
Power Rating	4.1 Kw	10 Kw	25 Kw	100 Kw	225 Kw
Max. Avg. Power at 1300 Hours	2.1 Kw	1.8 Kw	3.2 Kw	8.6 Kw	19.5 Kw
Min. Avg. Power at 0100 Hours	1.1 Kw	0.8 Kw	1.5 Kw	3.5 Kw	7.9 Kw
Max. Avg. Power in March	2.0 Kw	1.7 Kw	3.2 Kw	8.6 Kw	19.5 Kw
Min. Avg. Power in August	0.8 Kw	0.5 Kw	0.9 Kw	1.9 Kw	4.4 Kw
Avg. Yearly Power	1.5 Kw	1.14 Kw	2.12 Kw	5.32 Kw	12.0 Kw
Avg. Yearly Energy	13140 Kwh	9986 Kwh	18571 Kwh	46603 Kwh	105120 Kwh

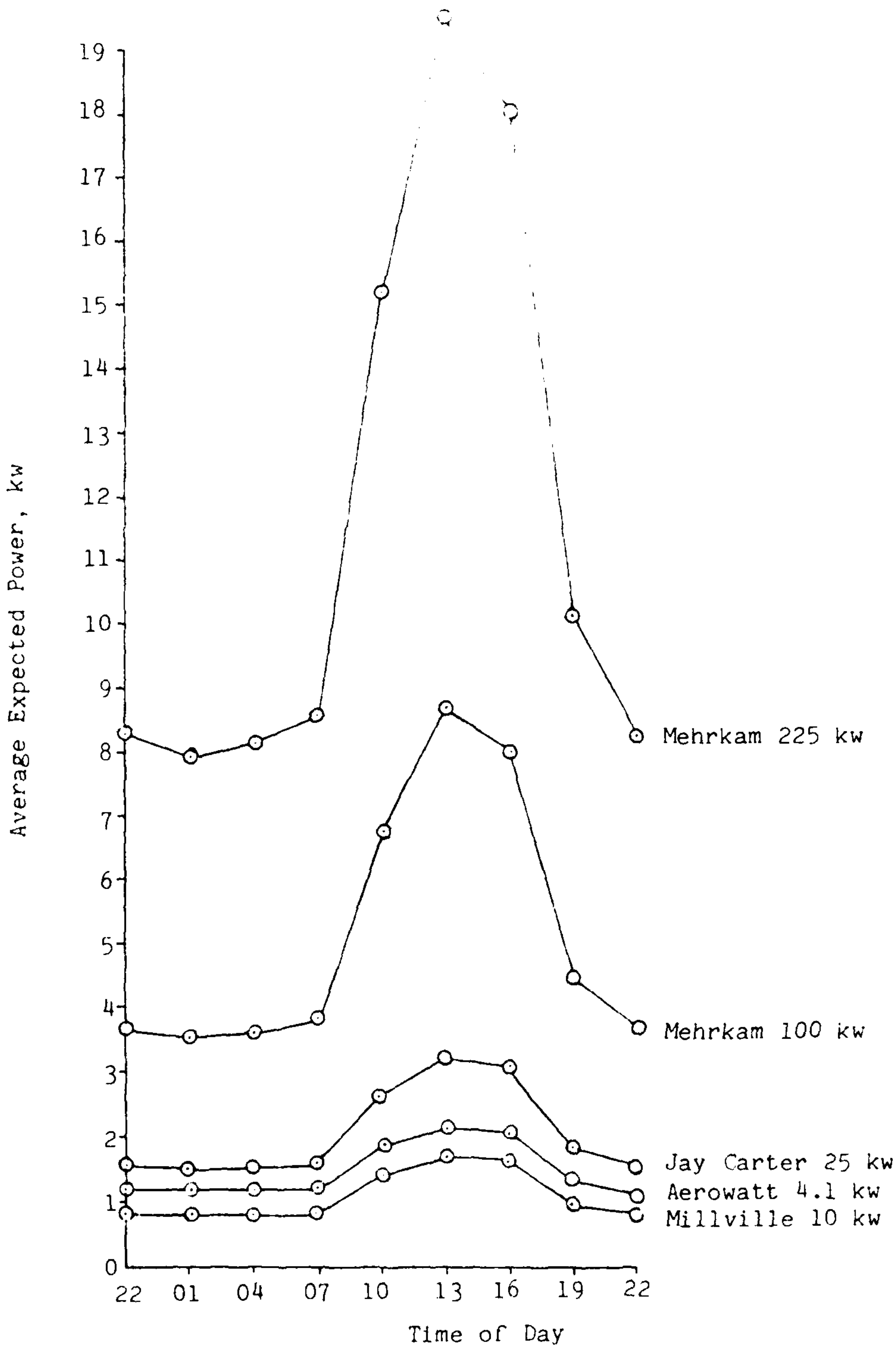


Figure B-1. Average Expected Power

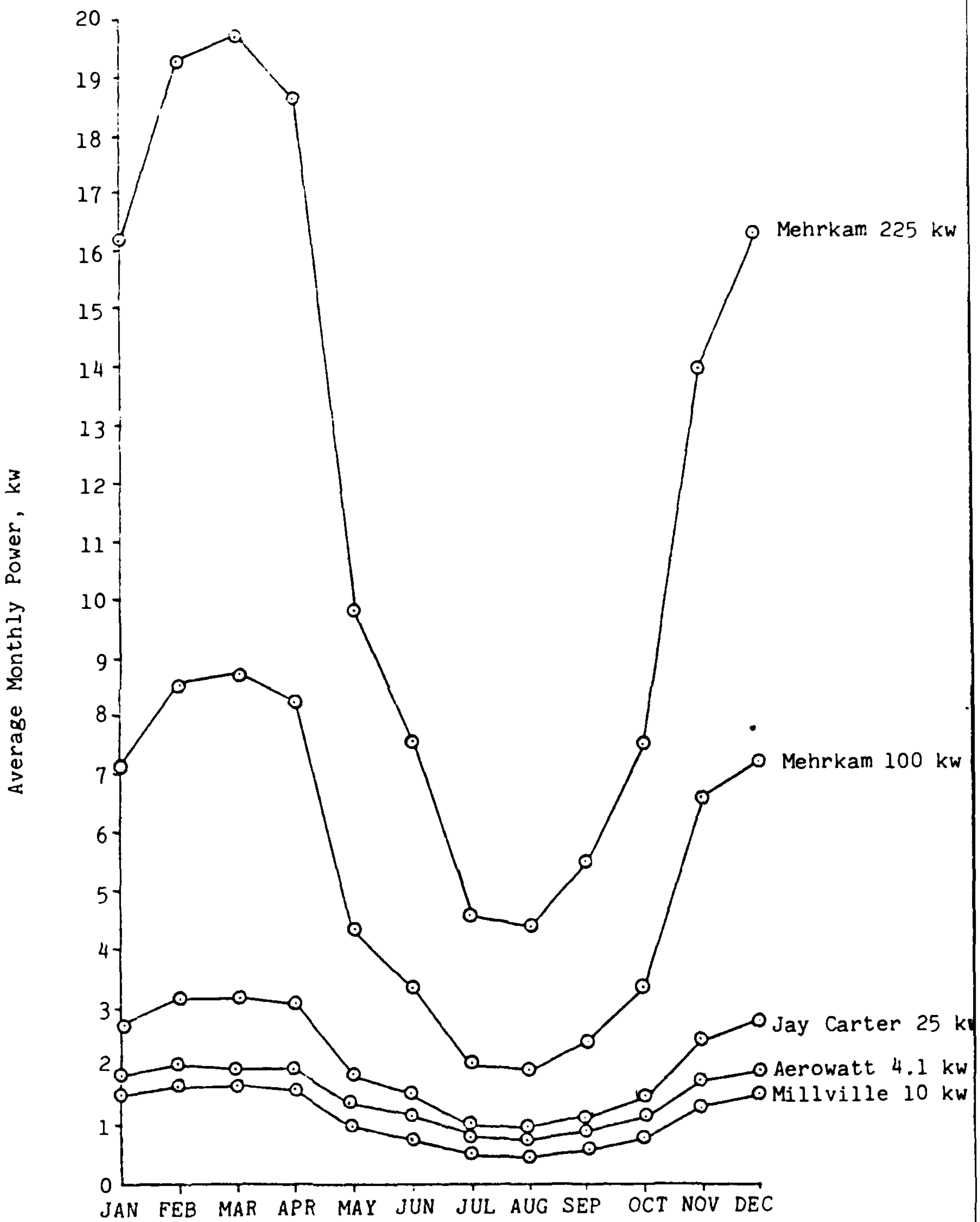


Figure B-2. Average Monthly Power Versus Month

2. PRELIMINARY ECONOMIC ASSESSMENT OF WIND MACHINES

The final set of options for renewable energy systems to be suggested for the Flight Dynamics Laboratory at Wright-Patterson will, of course, provide a match between the system components (wind, solar thermal, photovoltaic, etc.,) and the various identified existing laboratory loads. However, a preliminary assessment of the economic value of the five selected wind turbine machines can be made by considering the power each generates to be a simulated load and leave to a later date the incorporation of any aspects which may be learned from these simulations to aid in suggesting the appropriate machine for the actual loads.

The discussion of wind generators to this point has not dealt with economic factors, but rather has been concerned with the physical assessment of what wind resource exits at WPAFB and what average power various sized machines could extract from this wind resource. The decision of whether or not to invest in a wind turbine capital asset will ultimately be based on the determination of whether the investment generates sufficient revenues to cover all costs including the cost of capital. This determination is typically made using one of the discounted cash flow models which relate the cash flows generated by an asset to a minimum return criterion. The specific form of discounted cash flow model which will be used in this analysis is the Annual Equivalent Cost (see Reference 12).

The assessment of the economic value of each of the five selected wind machines will be made by determining the cash flow which would result in combining the annual costs incurred by a specific machine with the annual funds generated by that machine if the energy it produced were sold at a commercial energy rate of $0.0525/kwh (approximate cost of power at Wright-Patterson Air Force Base). Each machine was assumed to have a utilizable life of 20 years so the annual equivalent costs are also over that time period. Other assumptions made were that the cost of money will be 10%, annual operation and maintenance will be

2.5% of the installed cost and allowed to escalate with the price of energy sold, and energy sold will be allowed to escalate at rates of from 6% to 12% per year.

Table B-3 contains the above mentioned economic data as well as the computed annual equivalent costs for the respective escalation rates considered. It can be seen from these results that all five machines would result in money lost if the assumptions made were correct.

TABLE B-3

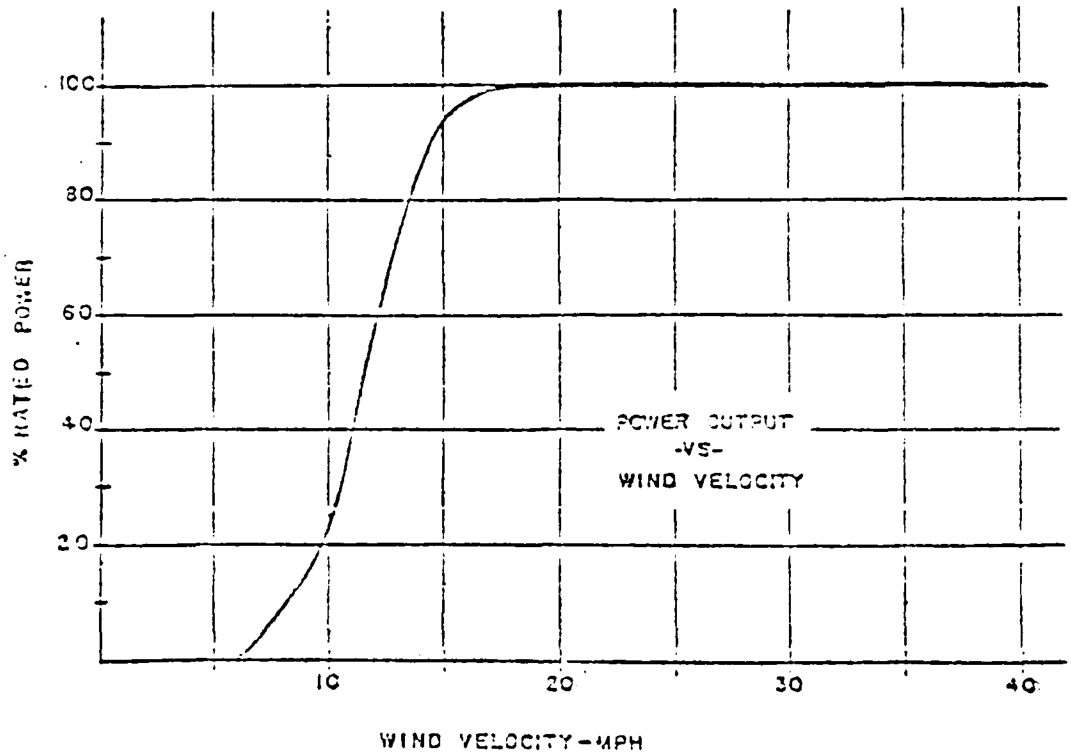
Preliminary Economic Assessment of Five Wind Turbines

All Live 20 years	AEROWATT 4.1 KW	MILLVILLE 10 KW	CARTER 25 KW	MEHRKAM 100 KW	MEHRKAM 225 KW
Base Price $	42,758.	11,150.	18,000.	80,000.	160,000.
Tower $	3,000.	3,064.	included	included	included
Installation $ (estimated)	3,000.	3,000.	3,000.	4,875.	6,400.
Total Initial Costs $	-48,758.	-17,214.	-21,000.	-84,875.	-166,400.
Annual Costs:					
Operation & Maintenace $ 2.5% of Initial	-1,219.	-430.	-525.	-2,122.	-4,160.
Value of Energy Generated $ $0.0525/KWH	+690.	+547.	+1,035.	+2,912.	+6,554.
Total Annual Costs $	-529.	+117.	+510.	+790.	+2,394.
Annual Equivalent Costs $ - considering interest at 10% and both Operation & Maintenance and Value of Energy escalating at rates per year of:					
6%	-6,589.	-1,831.	-1,636.	-8,683.	-15,646.
8%	-6,758.	-1,794.	-1,473.	-8,430.	-14,881.
10%	-6,970.	-1,747.	-1,269.	-8,114.	-13,921.
12%	-7.237.	-1,688.	-1,011.	-7,715.	-12,713.

MANUFACTURERS' OUTPUT CURVES FOR WIND TURBINES

AEROWATT

4100 FP 7G



Rated Output	4.1 KW
Rated Speed	16 mph
Cut In	4.5 mph
Cut Out	N/A
Rotor Diameter	30.7 ft
Axis	Horizontal
Output	48/120 VDC
Base Price	$42758
Tower	Not Included

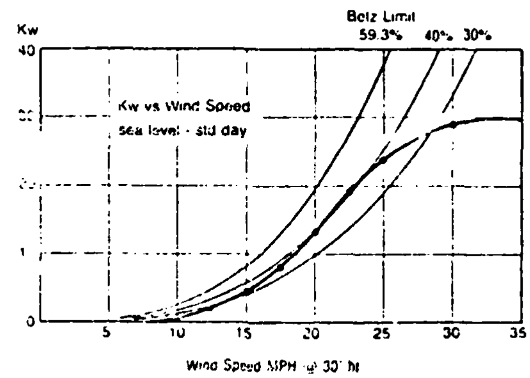
JAY CARTER

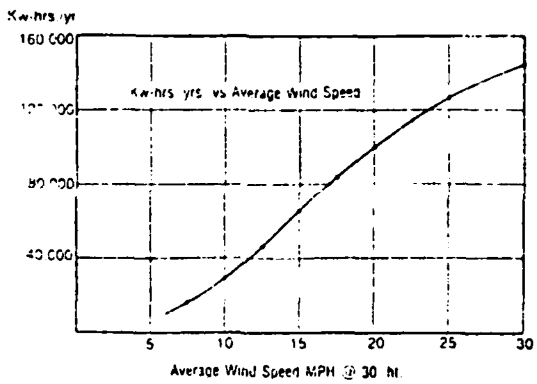
25 KW

MODEL 25 SPECIFICATIONS

Output

Minimum output - 7½ mph wind
Rated output - 25 kw in 26 mph wind
Max. output - 30 kw in approx. 30-40 mph wind



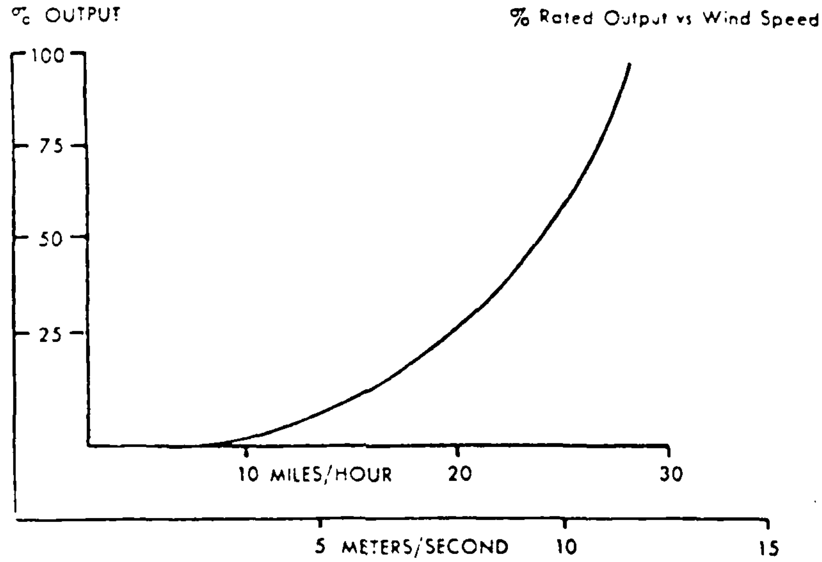


Rated Output	25 KW
Rated Speed	25 mph
Cut In	7.5 mph
Cut Out	125 mph
Rotor Diameter	32 ft
Axis	Horizontal
Output	220/440 VAC
Base Price	$18000
Tower	Included

MEHRKAM

4-100 and 4-225

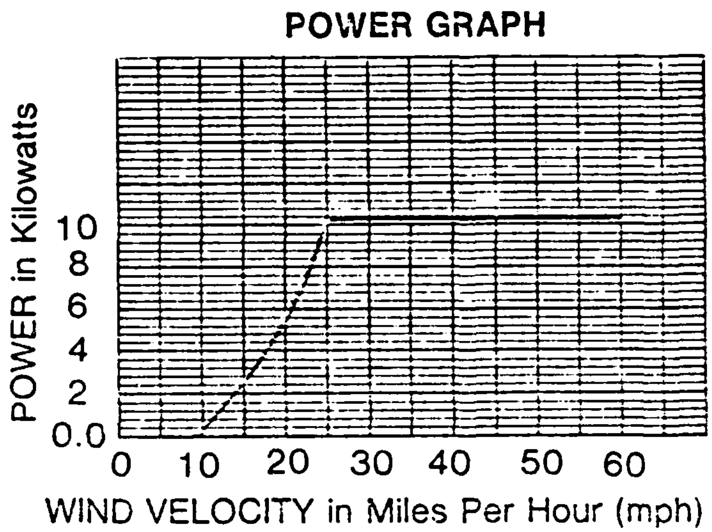
Typical Performance



	4-100	4-225
Rated Output	100 KW	225 KW
Rated Speed	28 mph	28 mph
Cut In	7 mph	7 mph
Cut Out	40 mph	40 mph
Rotor Diameter	not available	
Axis	Horizontal	Horizontal
Output	3 Ø, AC	3 Ø, AC
Base Price	$80000	$160000
Tower	Included	

MILLVILLE

103-IND

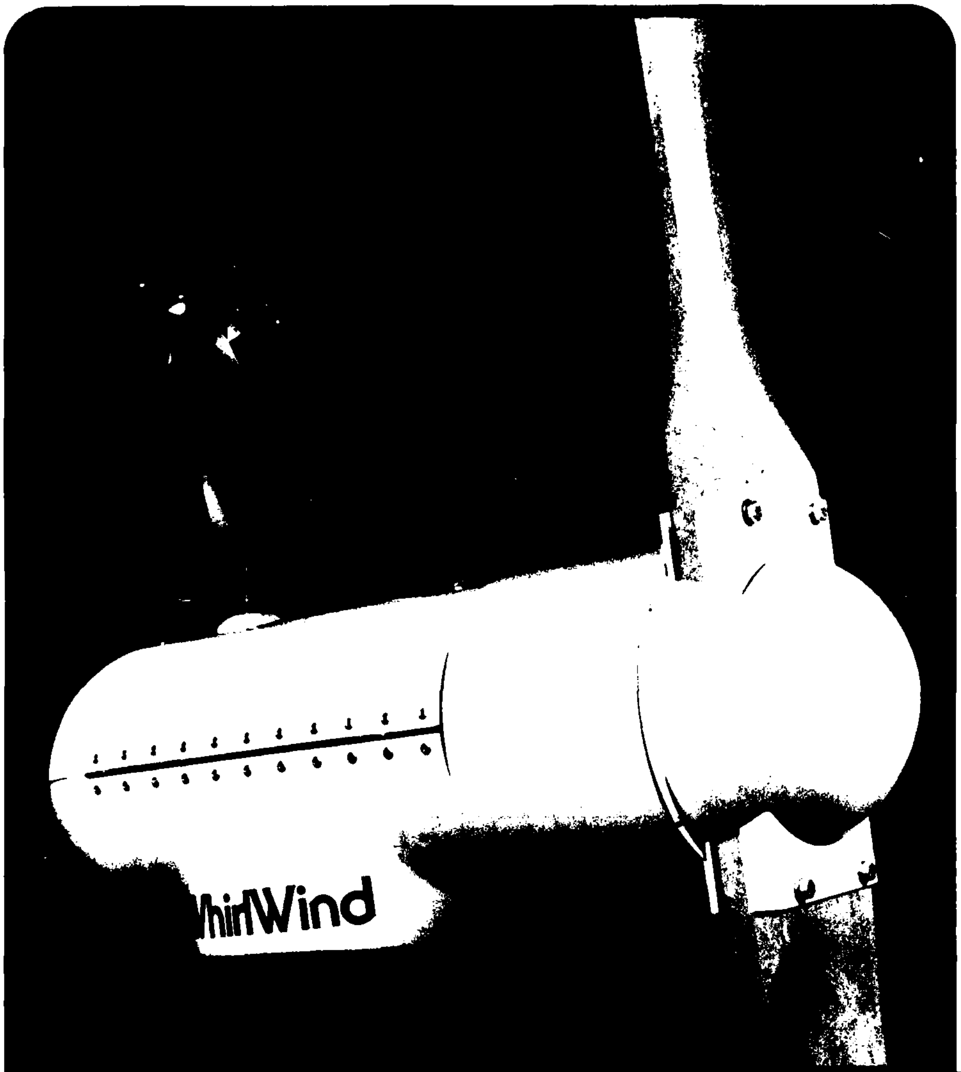


Rated Output	10 KW
Rated Speed	25 mph
Cut In	9 mph
Cut Out	60 mph
Rotor Diameter	24.3 ft
Axis	Horizontal
Output	240 VAC
Base Price	$10750
Tower	Not Included

APPENDIX C

MANUFACTURER'S INFORMATION

Whirlwind Model 3120 Wind Turbine



All New for 1982!

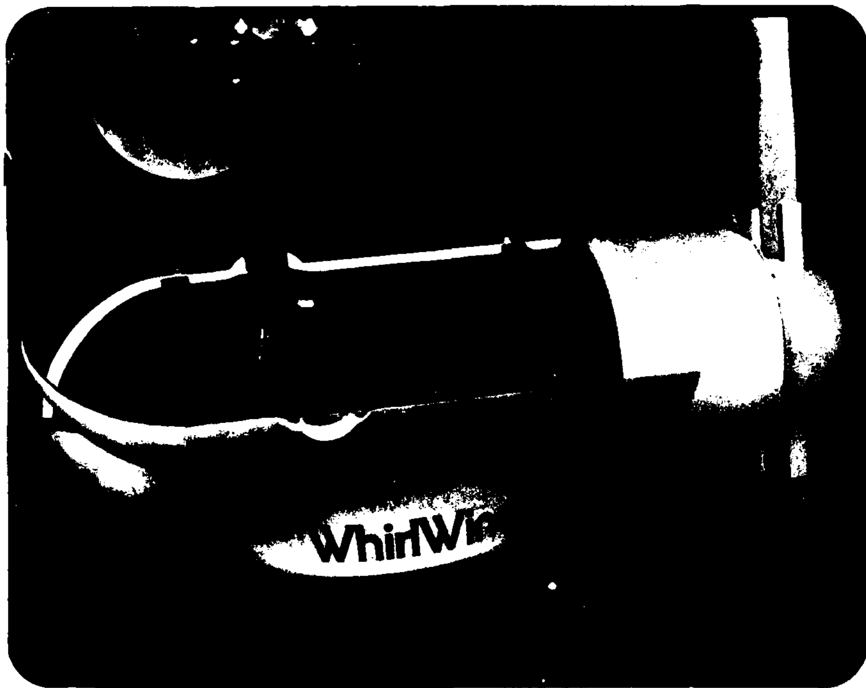
Economical, Reliable Wind Electric Systems For Home, Business and Remote Power Needs.

WhirlWind Series 3000

3 KW Wind Generators

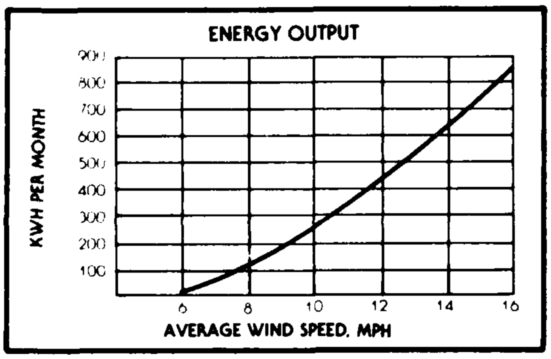
Design Features

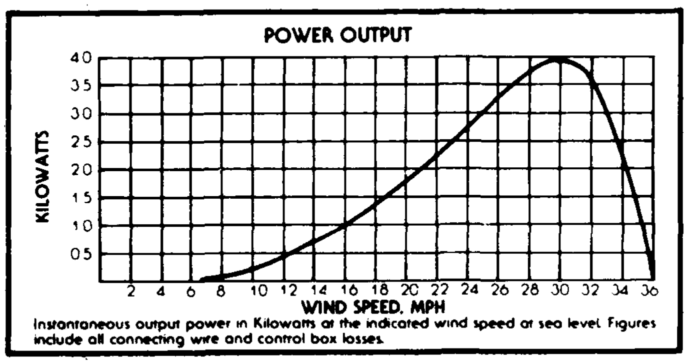
- Self starting — no power wasted to start or stop rotor.
- Direct drive — higher efficiency, fewer moving parts to wear out.
- Inside-out alternator — eliminates slip rings and brushes.
- Permanent magnet field — no wasted field power, anti-cog design for easy propellor start-up.
- Alternator rotor and propellor hub are combined in a unique single assembly for increased strength and significant weight reduction.
- Three phase alternator and three phase power transmission to load — less weight and smaller wire from generator to load (or increased distance from generator to load).
- Every WhirlWind generator is ready to provide electric heat with only the addition of a tower.
- Automatic electronic control box — provides user with three phase AC for water or space heating and DC for battery charging or utility interface through a synchronous inverter. Charging regulator, priority selection, brake switch and full metering included.
- Tailless upwind design — less weight, no cumbersome tail to install, less tower shadow than downwind designs.
- Pilot rotor yaw drive — orients machine to wind direction as if it had a tail, turns machine sideways in high winds as if it had a folding tail. "Just like magic," exclaims a delighted owner. Rugged, all mechanical design with no electronics or hydraulics.
- Yaw rate limiting — makes possible the vibration-free utilization of a two bladed propellor.
- Two bladed propellor — less weight and higher efficiency than three bladed designs.



Series 3000 Specifications

Propeller:	Two blades, one piece, Sitka spruce, 14 foot diameter.	
Alternator:	18 pole, three phase, ceramic permanent magnet, slow speed, direct drive.	
Weight:	Tower top total — 230 lbs.	
Wind Speeds: (sea level)	Cut-In	7-8 mph
	Rated power	26 mph
	Peak Power	30 mph
	Governing	26-36 mph
	Shutdown	36 mph
	Survival	120mph
Rated Power:	3 Kilowatts	
Peak Power:	4 Kilowatts	
Maintenance:	Lubrication and inspection every two years. All moving parts easily replaceable.	
Warranty:	Two years, parts and labor.	





Instantaneous output power in Kilowatts at the indicated wind speed at sea level. Figures include all connecting wire and control box losses.

Model 3032

This model is designed specifically for 30 or 32 volt battery charging or may be used without a battery for water or space heating. Charging is fully regulated for longest battery life. Extra power is automatically sent to an electric heater when the battery is full. This is our most popular generator for independent wind electric systems, and more accessories are available every day such as lights and appliances that run directly from the battery and inverters in all sizes to provide 120/240 vac from the battery. The Model 3032 is also designed to charge a 24 or 36 volt battery at slightly less output.

Model 3120

This model is designed specifically to reduce the homeowner's electric bill. It is also used for 120 volt battery charging and for water or space heating. With the generator interfaced to the utility, the typical family can expect a 50% reduction in electric bills in a 10 to 12 mph average wind.

Complete Catalog

WhirlWind Power Company provides a complete line of accessories for the Model 3032 and 3120 wind generators including self-erecting, free standing and guyed towers, batteries, inverters and battery operated appliances and lights. Our catalog includes a complete wind electric system planning guide, applications information on the Models 3032 and 3120 and descriptions of all our accessories. Please send $2.00 (domestic mailed) or $3.00 (foreign mailed).

WhirlWind
Power Company

Manufacturing Plant
5030 York Street
Denver, CO 80216
(303) 595-8491

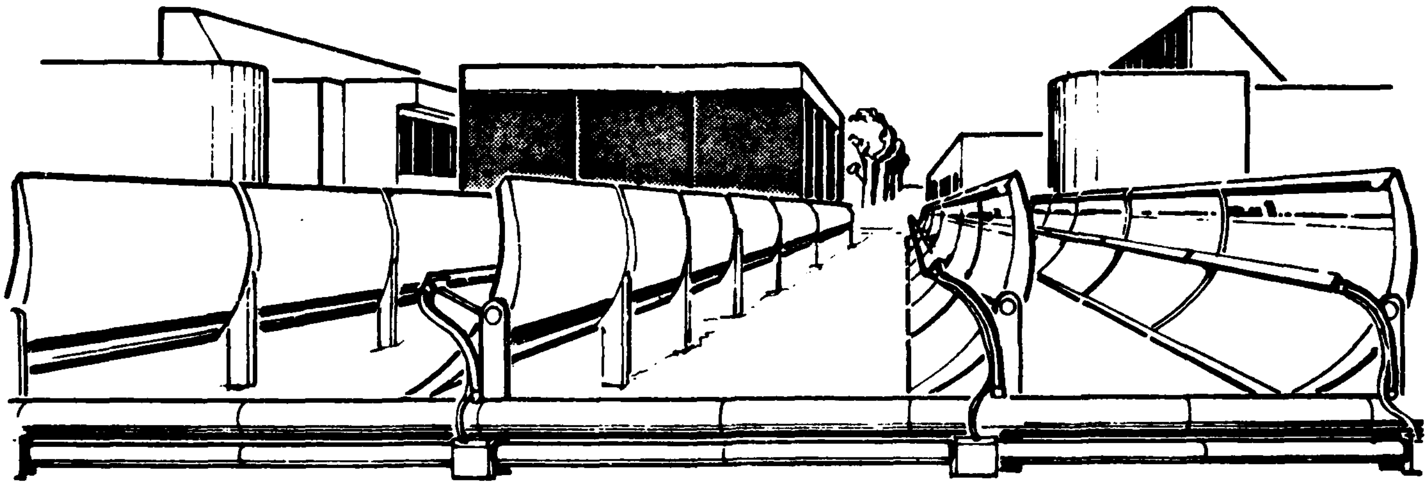
SEE YOUR AUTHORIZED DEALER

APPENDIX D

TECHNICAL DATA FOR SOLAR KINETICS, INC.

T-700 Collector

TECHNICAL DATA



SOLAR KINETICS INC.

3300 CENTURY CIRCLE, IRVING, TEXAS 75060 214-721-1070

COLLECTOR DESCRIPTION

The T-700 solar collector is the result of over four years of design and development. Many design features set the T-700 apart from other collector types. Those features are as follows:

PERFORMANCE

Since the receiver area of a concentrating collector is less than the solar aperture, the thermal losses are less than expected for a non-concentrating collector such as a flat plate. For this reason the instantaneous efficiency of the T-700 is far greater than for flat plates, especially during low solar flux periods such as hazy days.

The net thermal output of tracking collectors is greater than that of static collectors since the tracking unit intercepts a greater quantity of solar flux. When increased efficiency is coupled with increased solar availability due to tracking, the result is substantially improved thermal output.

A concentrating collector uses only direct normal insolation while a flat plate or evacuated tube collector can use diffuse and reflected light as well. On the surface this would seem to indicate that flat plates would perform better on cloudy days than the T-700 but such is not always the case. While the direct sunlight available to the T-700 would possibly be less than the combined light falling on the flat plate the latter may have substantially lower efficiency and therefore the total net output from the T-700 would be more. At 200°F when a shadow is slightly noticeable the T-700 will outperform most non-concentrating non-tracking collectors.

MATERIAL OF CONSTRUCTION

The use of precision machined, cast aluminum bulkheads, extruded aluminum edge formers and monocoque sheet metal construction* was based primarily on the desire to provide long unit life in the initial stages of solar energy equipment development. The selection of known fabrication techniques with known use life periods is, in our opinion, a reasonable approach to mirror fabrication. The torsional rigidity of this structure is exceptionally high and quality control for the components of this system of construction can be effective through known techniques.

ANGULAR MISALIGNMENT

This feature, not found on other parabolic trough collectors will prevent tracking drive loads which develop due to shifting of the pylon base. Installation misalignments also will not cause a bind on the tracking drive mechanism. Should the ground or building under the T-700 shift, the collector will continue to operate at misalignments of up to 5°

*U.S. PATENT NO. 4,240,406

HAIL RESISTANCE

The mirror substrate is T-6 X 0.040″ aluminum sheet which provides far greater protection than 0.040″ Alzac which was accepted by Sandia's Solar pumping facility as hail resistant. Alzac is not tempered and has a much lower yield than T-6 heat treated aluminum. Solar Kinetics'collectors have endured ¾″ hail stone storms undamaged.

REFLECTIVE SURFACE

3-M's FEK-244 with average specular reflectivity of 83% was chosen. Solar Kinetics, Inc. has conducted weather testing for 5 years on 3-M 5400 and 4 years on FEK films with less than 4% specular loss. No other unsatisfactory changes have been observed. The samples were tested in Dallas, Texas from ambients of 10°F to 110°F and in weather which included snow and hail.

RECEIVER TUBE

The reflective surface focuses on the receiver tube which is 16 gauge steel tubing. The selective surface is black chrome on nickel substrate with absorptivity of .96 and emissivity of .12 @200°C. The receiver tube is insulated by a Pyrex glass tube. The annulus between the receiver and the glass jacket is dry air. Receiver removal can be accomplished by loosening two fittings.

SOLAR TRACKING

The T-700 can accept analog signals from any type tracking demand control system whether it be microprocessor with precision shaft encoders or differential shadow bar devices.

The standard tracker developed by SKI uses the shadow well concept.

HYDRAULIC TRACKING *

Hydraulic tracking actuation has been chosen for several reasons.

All mechanical tracking mechanisms will develop backlash when exposed to continuous wind buffeting loads. Hydraulics eliminates this type of backlash as well as providing a slight cushioning effect to sudden loads. Repair and maintenance to the hydraulic components need not cause lengthy down time since the components can be readily replaced and repaired.

Tracking speeds are adjustable by the operator. Two speed tracking is provided through the use of bypass solenoid valves. This allows rapid stow at the onset of storms. Stored hydraulic pressure provides stow power with AC line power loss.

*U.S. PATENT NO. 4,178,913

SHORT FOCAL LENGTH

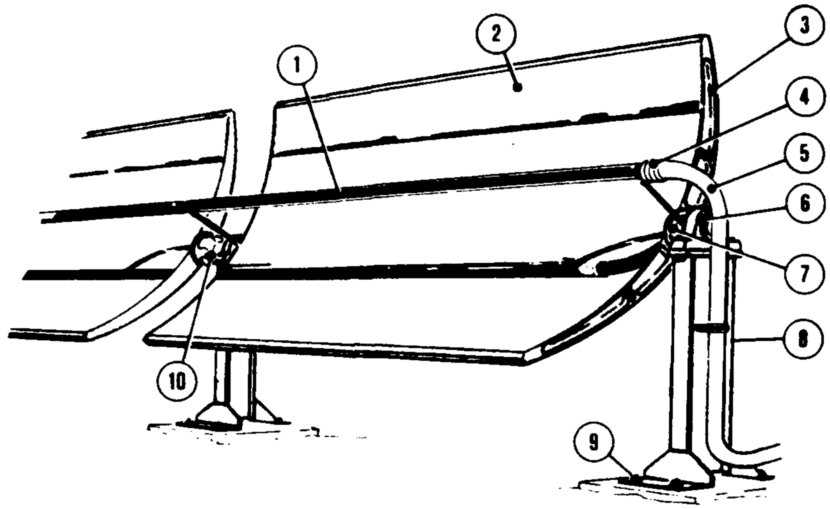
The true test of parabolic trough collector efficiency is not the instantaneous efficiency at solar noon, but rather, the all day efficiency curve. In the early and late hours of the day (for an East-West oriented collector) losses are experienced due to the cosine effect of the angle of the sun, but in addition to those losses, rapidly increasing focal lengths cause reflective errors greater than the diameter of the receiver tube. These losses are unavoidable if long focal lengths are chosen which require mirror accuracy beyond reasonable construction limits.

COLLECTOR ORIENTATION:

SKI collectors are horizontally mounted and oriented at any azimuth angle. The 260° angular acquisition capability of the SKI drive pylon allows focus at any solar angle and facilitates mirror cleaning and other maintenance activities.

Depending on seasonal cloud cover profiles, the north-south collector axis orientation delivers slightly more energy on an annual basis than the east-west (north-south tracking) setup. These two orientations deliver symmetrical daily output profiles with all other orientations producing output curves which favor either the morning or afternoon periods. Generally, the east-west orientation delivers about the same daily energy throughout the year while the north-south collectors produce most of the annual energy during the summer months with lower levels of delivered energy during the winter. Relative solar angles account for most seasonal and orientation output variations, since ambient temperatures do not markedly affect the T-700 performance. Collector field orientation should be designed to provide seasonal output profiles which follow load profiles where possible.

TECHNICAL DATA



Solar Kinetics' rigid monocoque* aluminum mirror and no-lash hydraulic tracking* along with proven engineering concepts provide long life and low cost. Features of the system are:

1. The black chrome plated steel receiver tube is surrounded by a dry air annulus protected by Pyrex® glass tubing. Focus is adjustable during installation.
2. A precisely constructed mirror surface is covered with metallized acrylic film, combining weather resistance and high reflectivity.
3. The parabolic contour of the cast aluminum ribs is N/C machine generated for an accurate focus.
4. The thermal expansion bellows allows for expansion of the receiver assembly and maintains a sealed, dry environment in the annulus.
5. An insulated stainless steel flex hose allows rotation of the collector with unrestricted flow.
6. Self aligning sealed ball bearings absorb structural loads maintaining collector motion without binding.
7. A steel flange carries torsional loads into the collector structure. Allows mirror installation with eight bolts.
8. The steel support pylon is galvanized for corrosion protection.
9. Mounting studs are a standard pattern for each collector.
10. This load bearing joint* protects the collector structure from strains induced by misalignment from foundation shifts.

*U S PATENT NO
4,178,913
4,240,406

SPECIFICATIONS	T-700	T-600
MODULE WIDTH	89.0 IN	53.0 IN
MODULE LENGTH	20 FT	20 FT
MIRROR WIDTH	84.5 IN	48.0 IN
SOLAR AREA	140 FT^2	80 FT^2
REFLECTANCE	0.84	0.84
MAX VERT HEIGHT	102 IN	65 IN
ROTATION AXIS HT	57 IN	39 IN
TRACKING ANGLE	260°	235°
STOW ANGLE	12°	45°
SYSTEM WEIGHT	4.0 LB/FT^2	4.0 LB/FT^2
RECEIVER TUBE	1.63 OD	1.63 OD
ANNULUS MEDIUM	DRY AIR	
SELECTIVE SURFACE	BLACK CHROME	
ABSORPTIVITY	0.94-0.97	
EMISSIVITY	0.18 @ 500°F	
RECEIVER COVER	PYREX GLASS	
MAX OPER TEMP	600°F	
MAX OPER PRESS	250 PSI	

TECHNICAL DATA

SOLAR COLLECTOR EFFICIENCY vs TEMPERATURE

Solar Flux — 290 BTU/ft²/hr
(924 Watt/M²)
Wind Speed — 8-12 MPH (13-19 Km/hr)
Fluid — Therminol T-66
Flow Rate — 5 GPM (19 L/min)
Aperture — T-700 — 140 ft² (13M²)
T-600 — 80 ft² (7.4M²)
Orientation — Normal to Sun
Receiver Annulus — Dry Air